



GFSSP

GENERALIZED FLUID SYSTEM

SIMULATION PROGRAM

- Version 5 (Beta Release)

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ER43/NASA/MSFC

Users Group Meeting

October 26, 2004

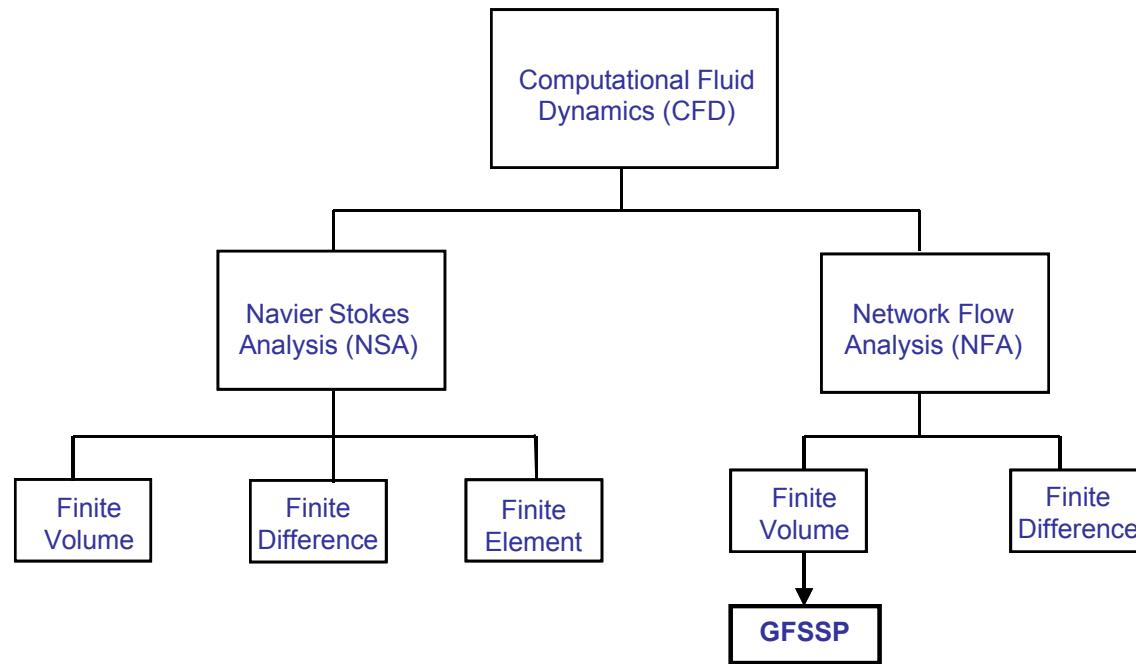


Topics

- GFSSP Overview
- New Features of Version 5
 - Conjugate Heat Transfer
 - Improvements in
 - Enthalpy Equation
 - Ideal Gas Option
 - VTASC
- Demonstration
- Applications



Classification of CFD Codes





GFSSP

Thermo-Fluid System Analysis Tool

Properties

- Fluids
 - Cryogenic
 - Propellants
 - Refrigerants
 - Air
 - Ideal Gas
 - Generic
- Solids
 - Metals
 - Alloys
 - Generic

Components

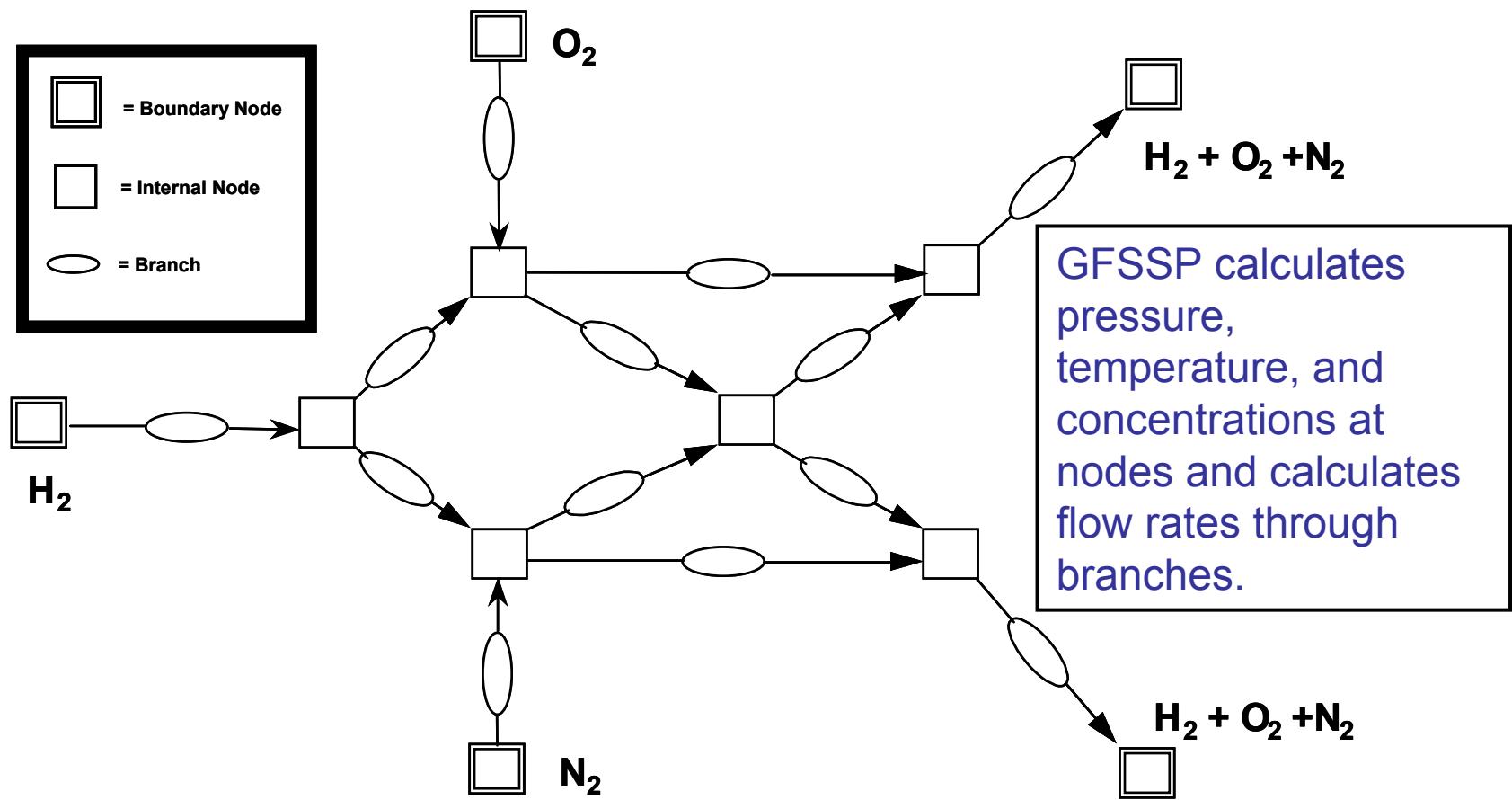
- Flow Resistances
 - Pipe
 - Fittings
 - Seals
- Pump
- Heat Exchanger
- Turbopump
- Control Valve
- Generic

Processes

- Mixing of Fluid
- Pressurization
- Blow down
- Choking
- Phase Change
- Water hammer
- Conjugate Heat Transfer

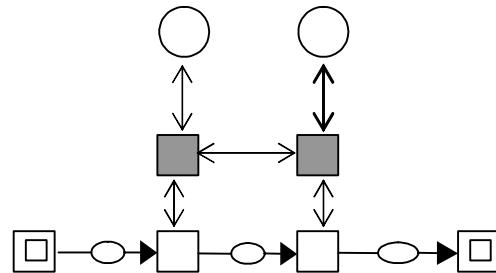


Finite Volume Formulation in a Fluid Network





Conjugate Heat Transfer



Boundary Node

Internal Node

Branches

Solid Node

Ambient Node

Conductor

Solid to Solid

Solid to Fluid

Solid to Ambient



Mathematical Closure

Unknown Variables

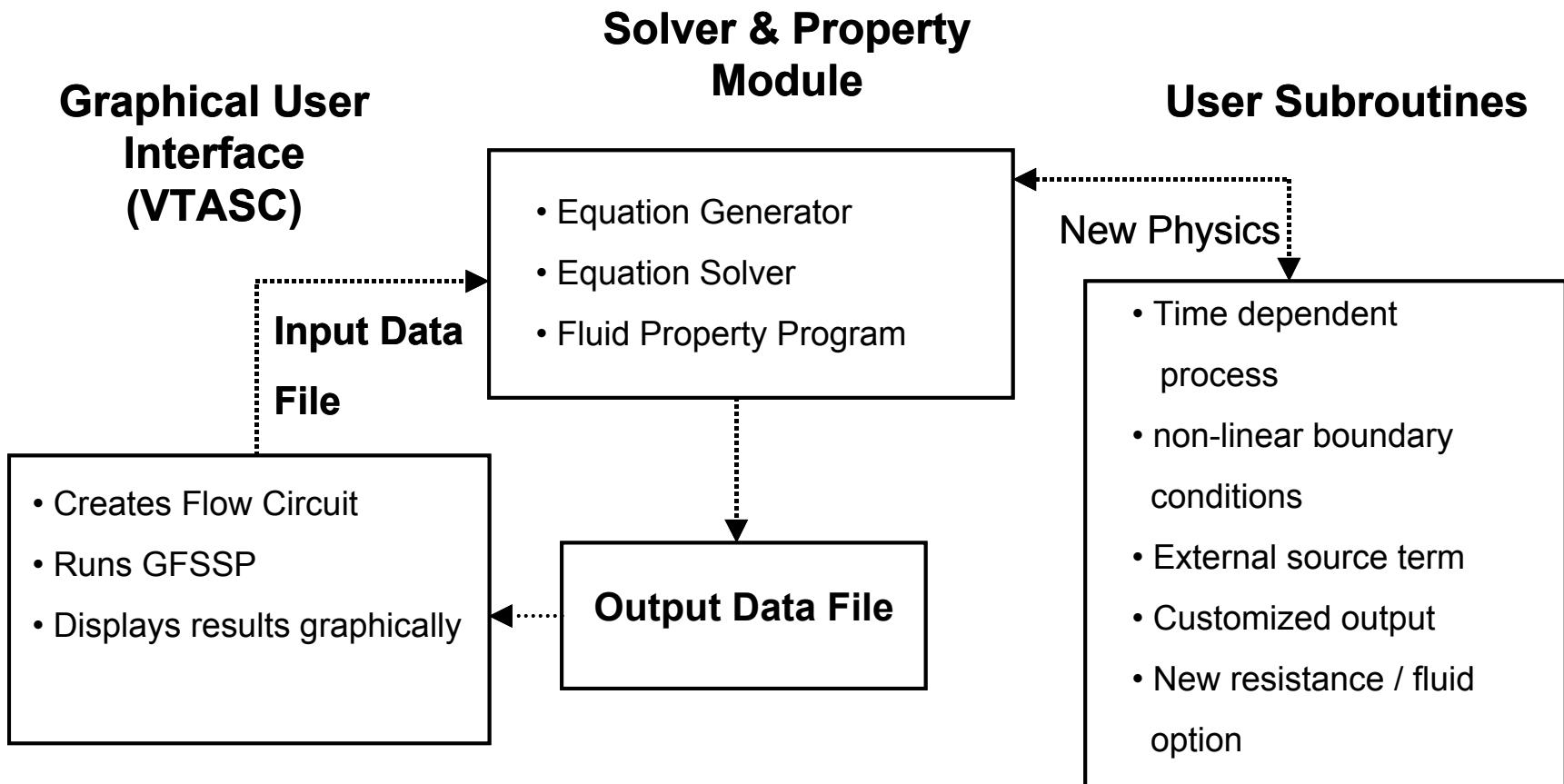
1. Pressure
2. Flowrate
3. Fluid Temperature
4. Solid Temperature
5. Species Concentrations
6. Mass

Available Equations to Solve

1. Mass Conservation Equation
2. Momentum Conservation Equation
3. Energy Conservation Equation of Fluid
4. Energy Conservation Equation of Solid
5. Conservation Equations for Mass Fraction of Species
6. Thermodynamic Equation of State



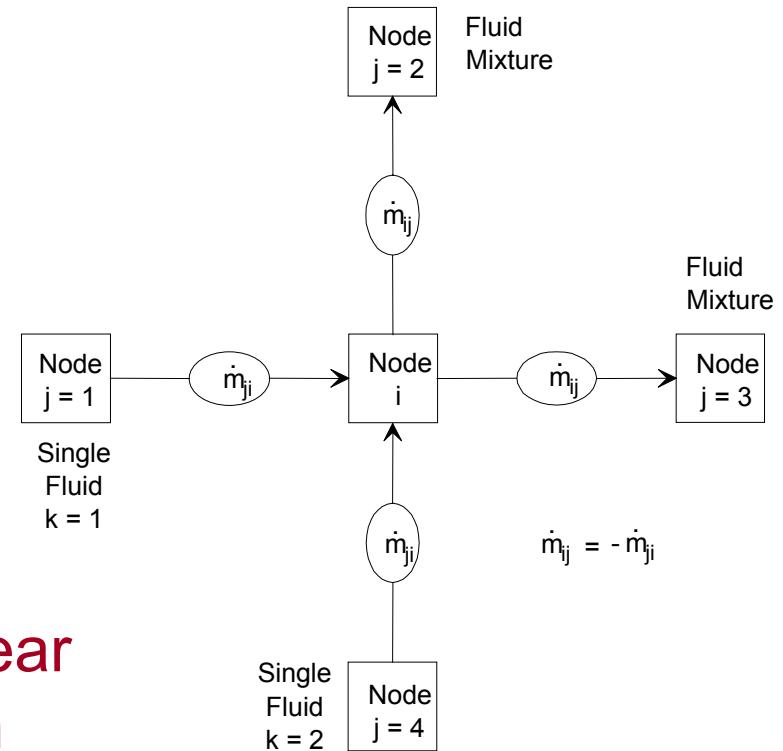
GFSSP – Program Structure





Mass Conservation Equations

$$\frac{m_{\tau+\Delta\tau} - m_\tau}{\Delta\tau} = - \sum_{j=1}^{j=n} \dot{m}_{ij}$$



Note : Pressure does not appear explicitly in Mass Conservation Equation although it is earmarked for calculating pressures

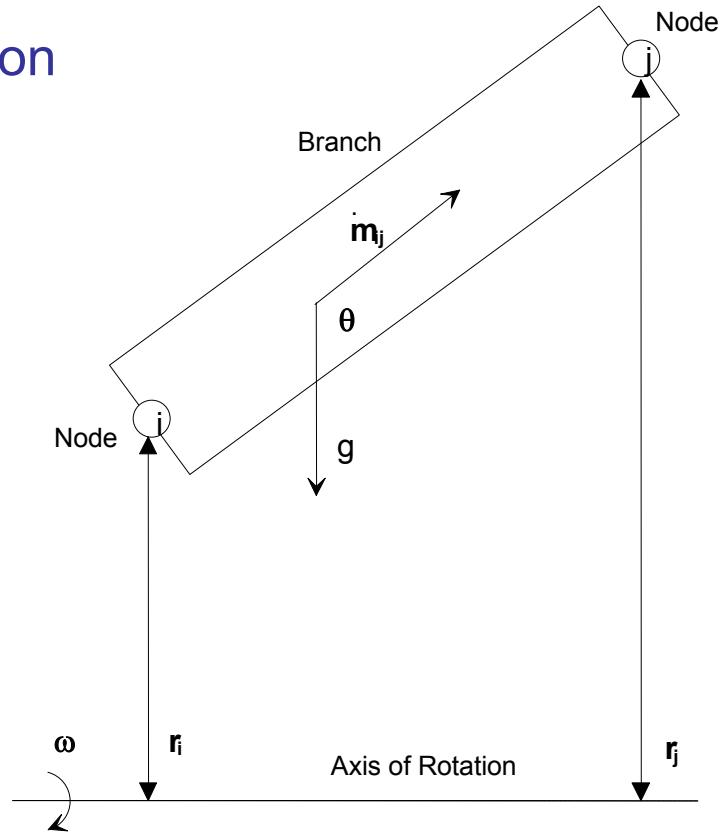


Momentum Conservation Equation

- Represents Newton's Second Law of Motion

$$\text{Mass} \times \text{Acceleration} = \text{Forces}$$

- Unsteady
- Longitudinal Inertia
- Transverse Inertia
- Pressure
- Gravity
- Friction
- Centrifugal
- Shear Stress
- Moving Boundary
- Normal Stress
- External Force





Energy Conservation Equation

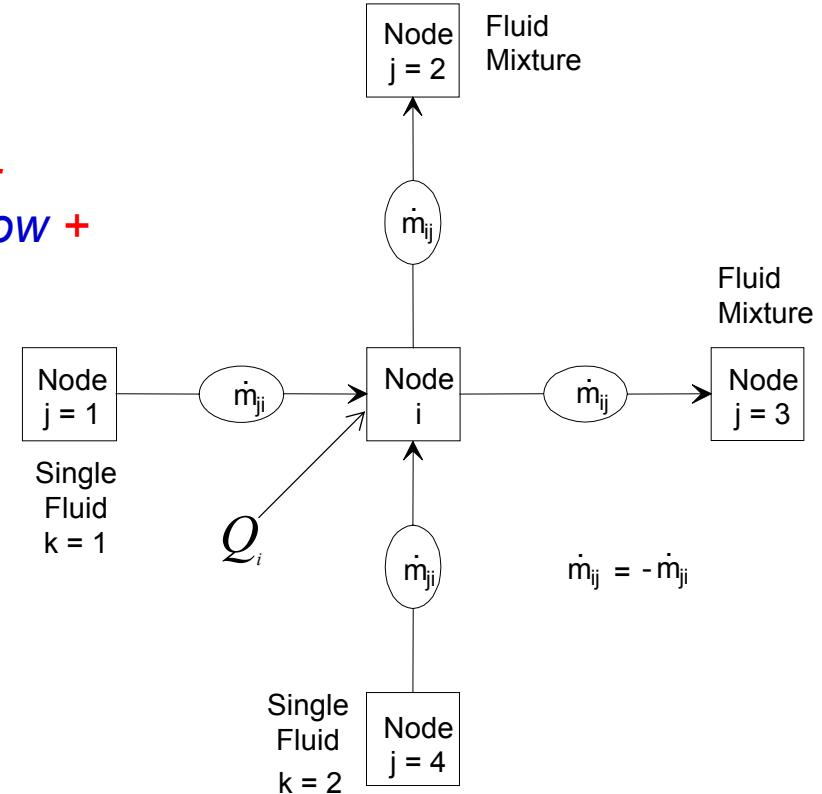
Rate of Increase of Internal Energy =

*Enthalpy Inflow + Kinetic Energy Inflow -
 Enthalpy Outflow + Kinetic Energy Outflow +
 Heat Source*

- Upwind Scheme for advection

$$\frac{m \left(h - \frac{p}{\rho J} \right)_{\tau+\Delta\tau} - m \left(h - \frac{p}{\rho J} \right)_\tau}{\Delta\tau} =$$

$$\sum_{j=1}^{j=n} \left\{ MAX \left[-\dot{m}_{ij}, 0 \right] (h_j + 0.5 \rho_j u_{ij}^2 / g_c) - MAX \left[\dot{m}_{ij}, 0 \right] (h_i + 0.5 \rho_i u_{ij}^2 / g_c) \right\} + Q_i$$





Equation of State

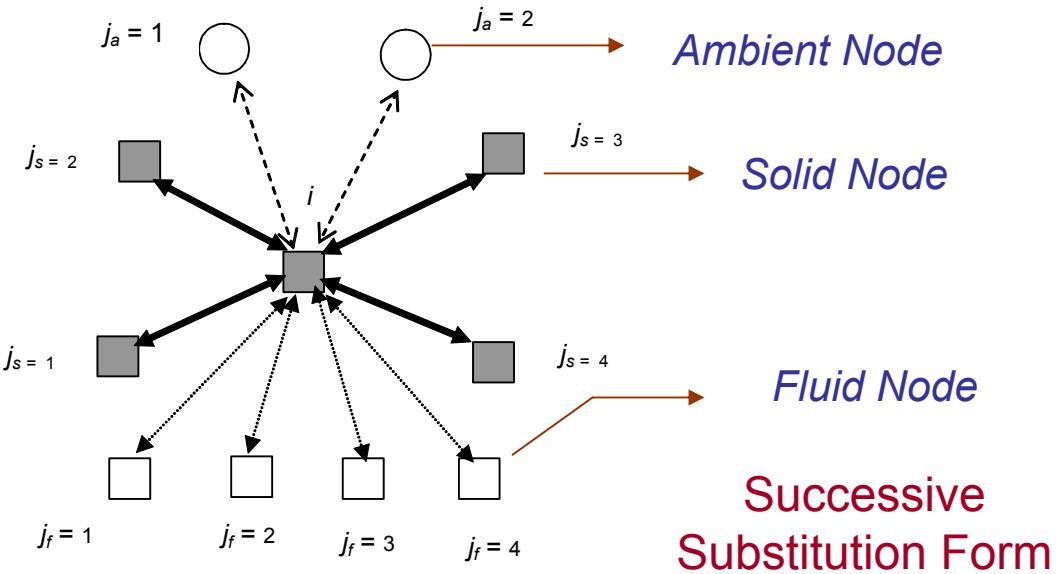
Resident mass in a control volume is calculated from the equation of state for a real fluid

$$m = \frac{pV}{RTz}$$

z is the compressibility factor determined from higher order equation of state



Heat Conduction Equation



$$\frac{\partial}{\partial \tau} (mC_p T_s^i) = \sum_{j_s=1}^{n_{ss}} \dot{q}_{ss} + \sum_{j_f=1}^{n_{sf}} \dot{q}_{sf} + \sum_{j_a=1}^{n_{sa}} \dot{q}_{sa} + \dot{S}_i$$

$$\dot{q}_{ss} = k_{ij_s} A_{ij_s} / \delta_{ij_s} (T_s^{j_s} - T_s^i)$$

$$\dot{q}_{sf} = h_{ij_f} A_{ij_f} (T_f^{j_f} - T_s^i)$$

$$\dot{q}_{sa} = h_{ij_a} A_{ij_a} (T_a^{j_a} - T_s^i)$$

$$T_s^i = \frac{\sum_{j_s=1}^{n_{ss}} C_{ij_s} T_s^{j_s} + \sum_{j_f=1}^{n_{sf}} C_{ij_f} T_f^{j_f} + \sum_{j_a=1}^{n_{sa}} C_{ij_a} T_a^{j_a} + \frac{(mC_p)_m}{\Delta \tau} T_{s,m}^i + \dot{S}}{\frac{mC_p}{\Delta \tau} + \sum_{j_s=1}^{n_{ss}} C_{ij_s} + \sum_{j_f=1}^{n_{sf}} C_{ij_f} + \sum_{j_a=1}^{n_{sa}} C_{ij_a}}$$

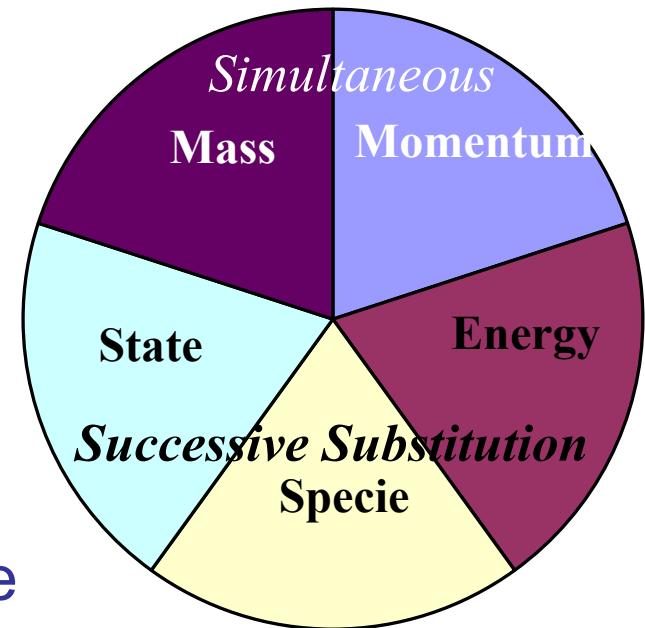


Solution Scheme

SASS : Simultaneous Adjustment
with Successive Substitution

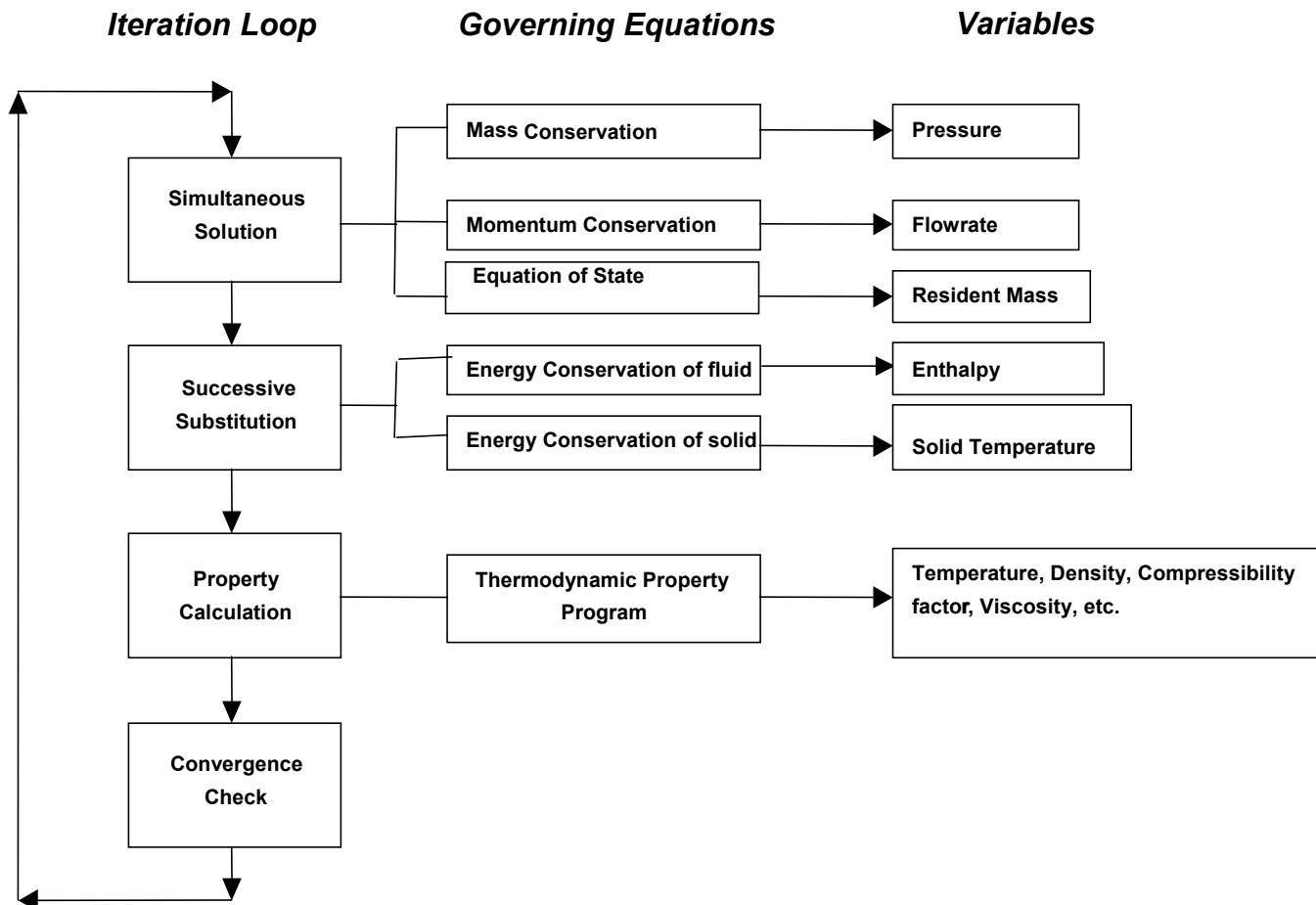
Approach : Solve simultaneously
when equations are strongly
coupled and non-linear

Advantage : Superior convergence
characteristics with affordable
computer memory



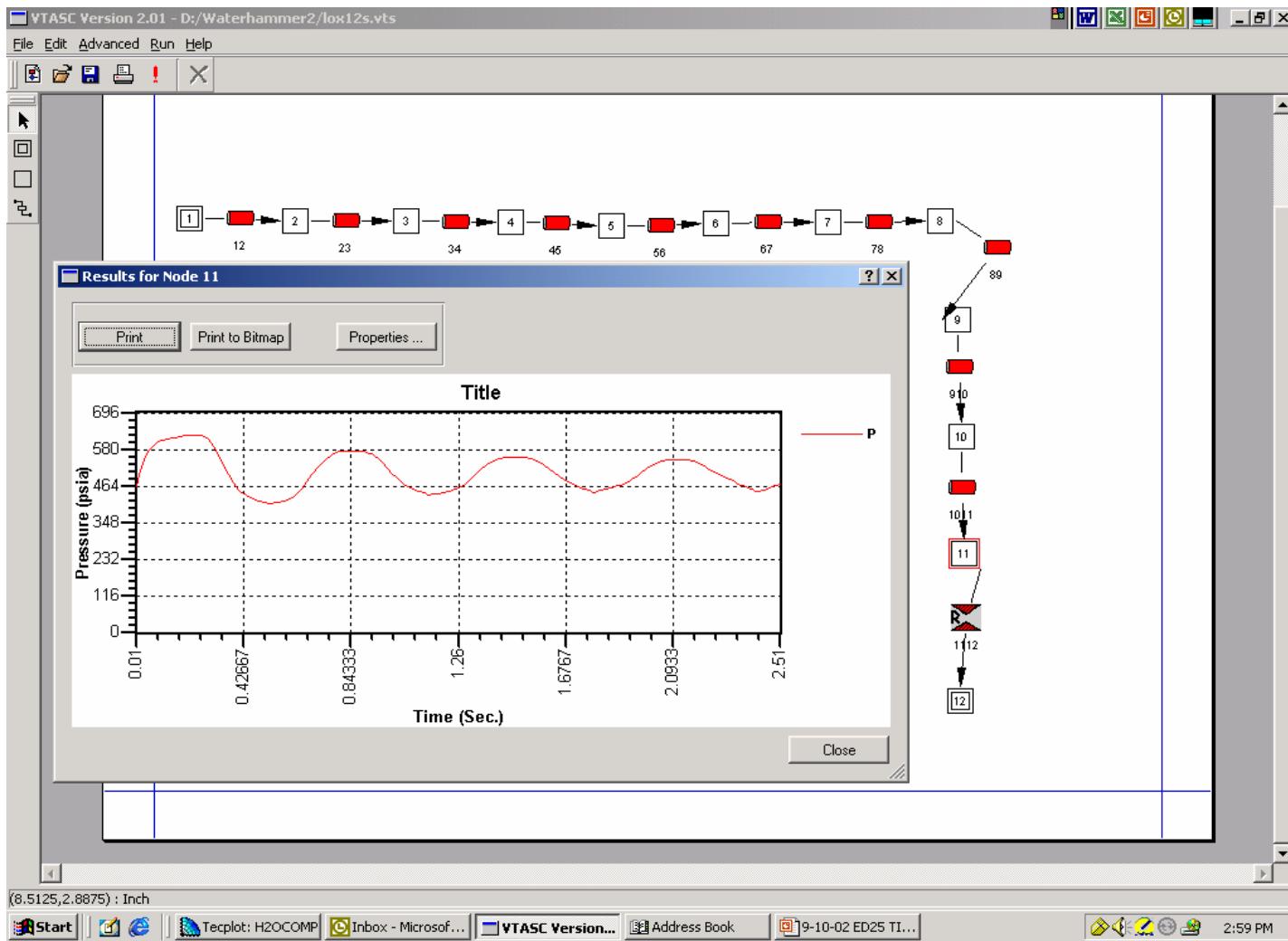


SASS Solution Scheme



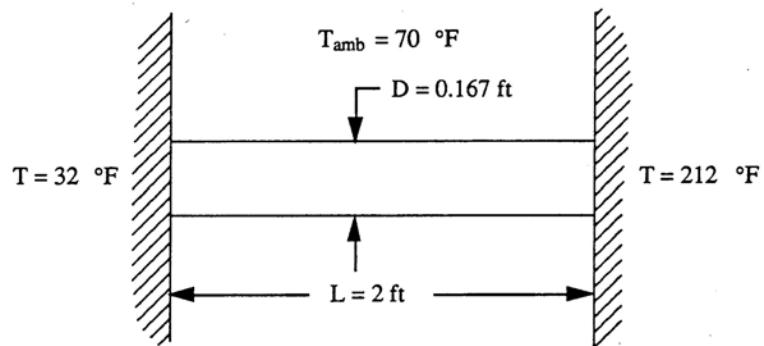


Graphical User Interface

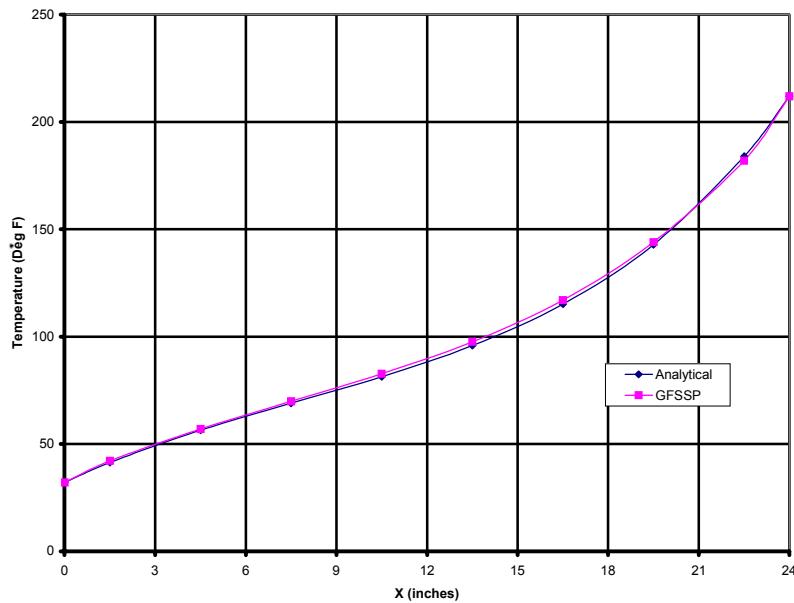




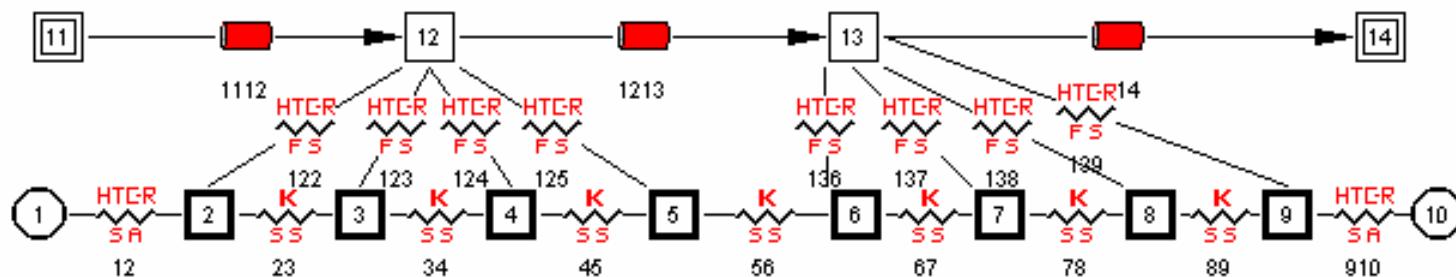
Verification of Conjugate Heat Transfer Results



Problem Considered



Comparison with Analytical Solution



GFSSP Model



Other Improvements

- Ideal Gas Option
 - Allows to chose new reference temperature and pressure
 - Allows mixture of ideal gas and real fluid
- VTASC
 - Conjugate Heat Transfer
 - Ideal Gas Option
 - Display of results
 - Use of default properties for resistance and conductor option



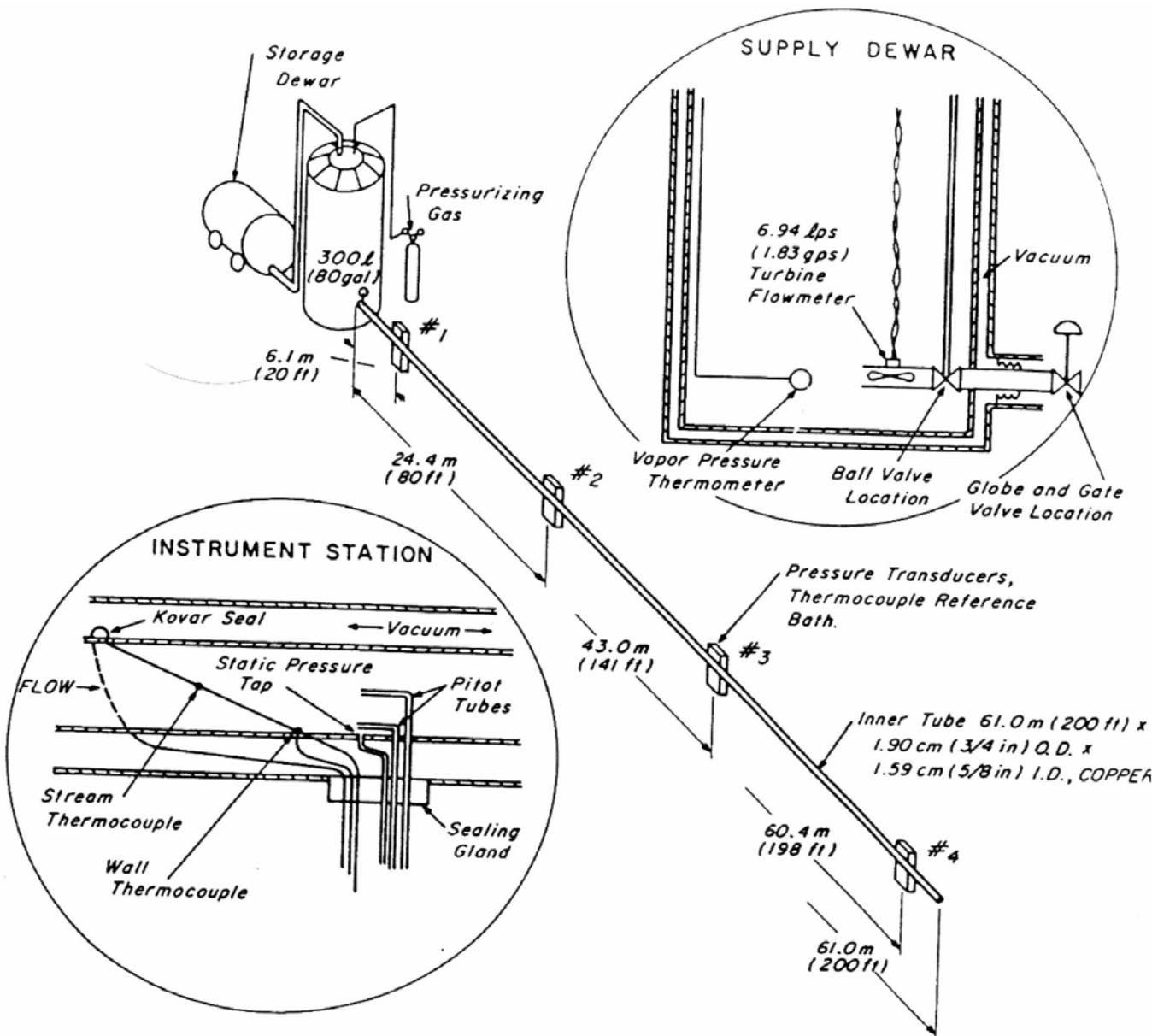
Summary

- The major highlight of Version 5 is
 - Conjugate Heat Transfer
- The other improvements are
 - Ideal Gas Option
 - Enthalpy Equation
 - VTASC Upgrade
- Work in Progress
 - Modeling of Boil-off and Fill-up of Cryogenic Tank
 - Modeling of Liquid Metal and Electromagnetic Pump
 - Chilldown of Cryogenic Transfer Line
 - Flow in Micro channel
 - Pressurization of Joint in Solid Rocket Motor
 - Cryo-pumping
 - Isentropic Flow in Nozzle

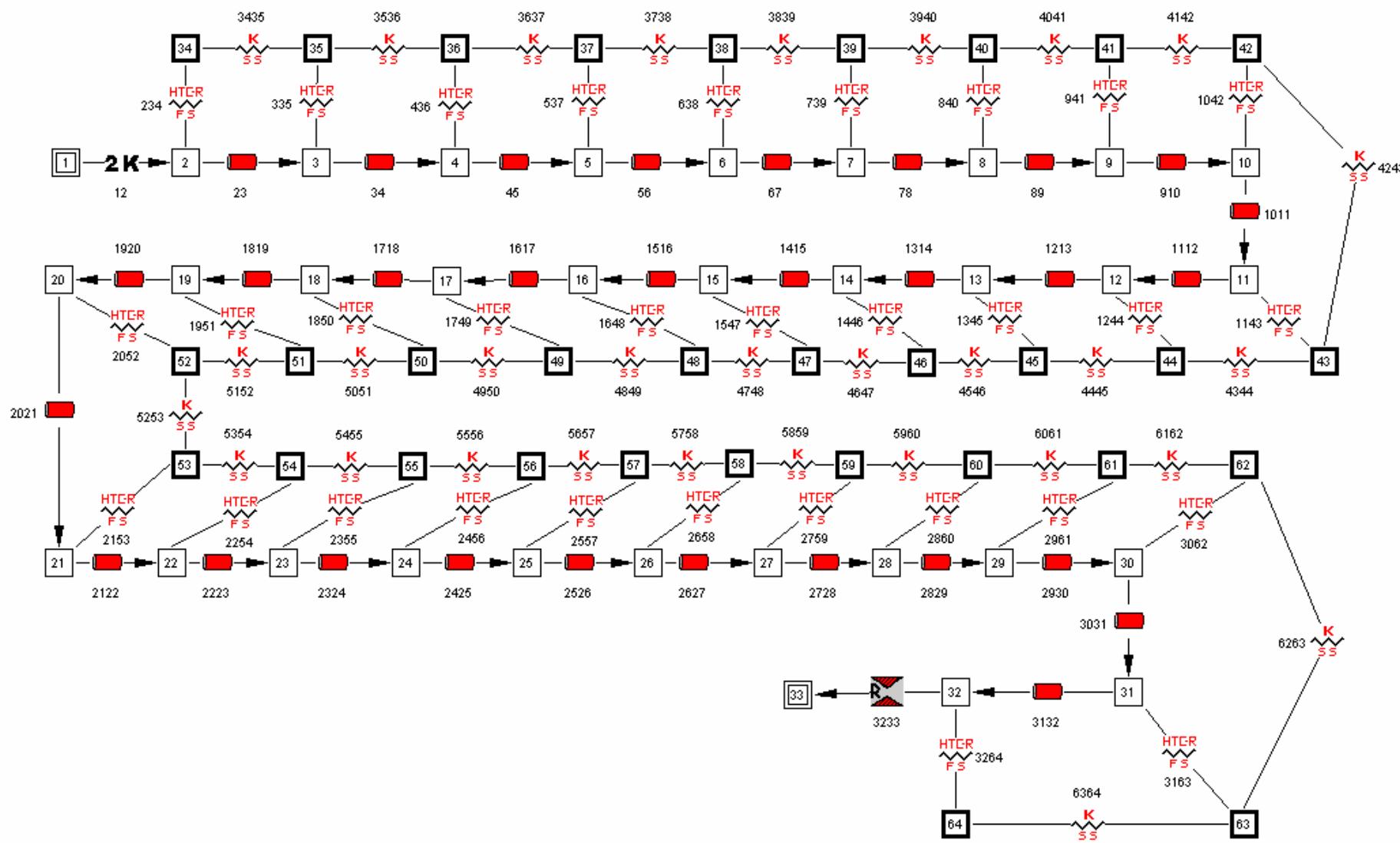
Numerical Modeling of Thermofluid Transients During Chilldown of Cryogenic Transfer Lines Update

Todd Steadman
Jacobs Sverdrup Technology, Inc.

Experimental Setup



GFSSP Model



Model Details

- Time Step = 0.0015 secs

$$\text{Courant Number} = \frac{L_b}{a\tau} = \frac{6.67 \text{ ft}}{\tau \cdot 3577 \frac{\text{ft}}{\text{s}}} \geq 1$$

- Upstream Boundary Conditions

Fluid: Liquid Hydrogen

P = 74.97 psia

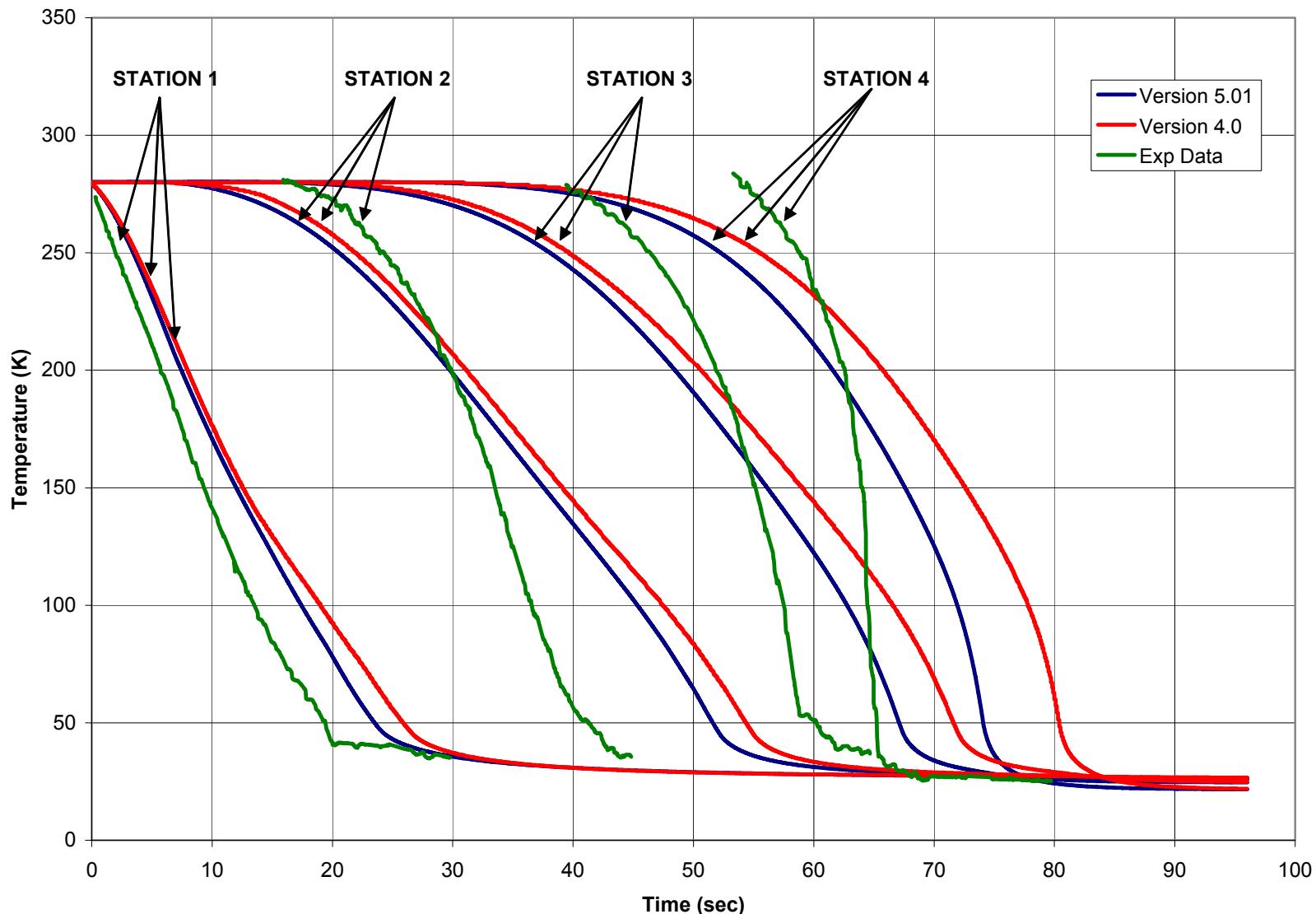
T = 48.6 R

- Pipe Characteristics

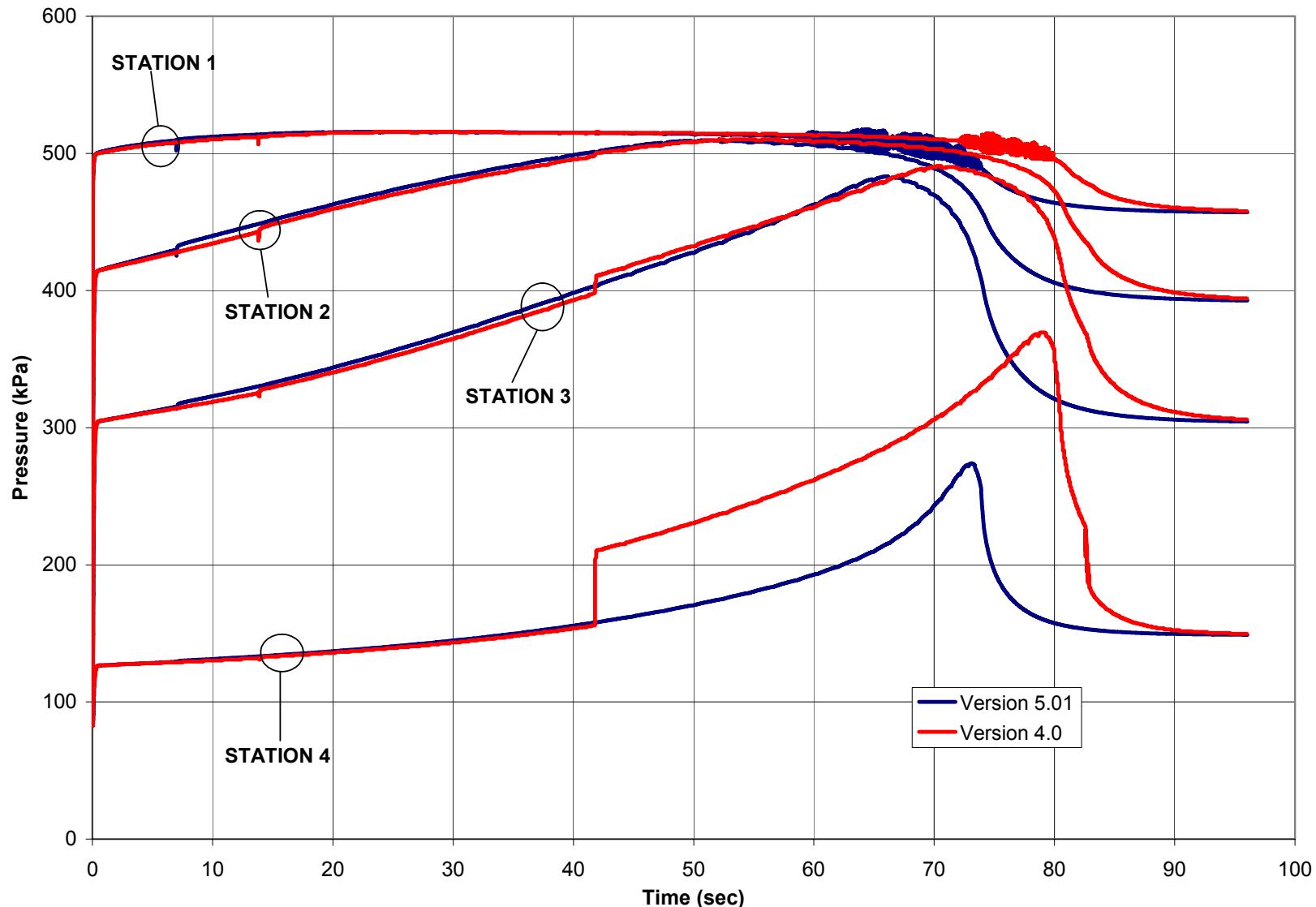
Material: Copper

1" Outside Diameter, 3/16" Wall Thickness

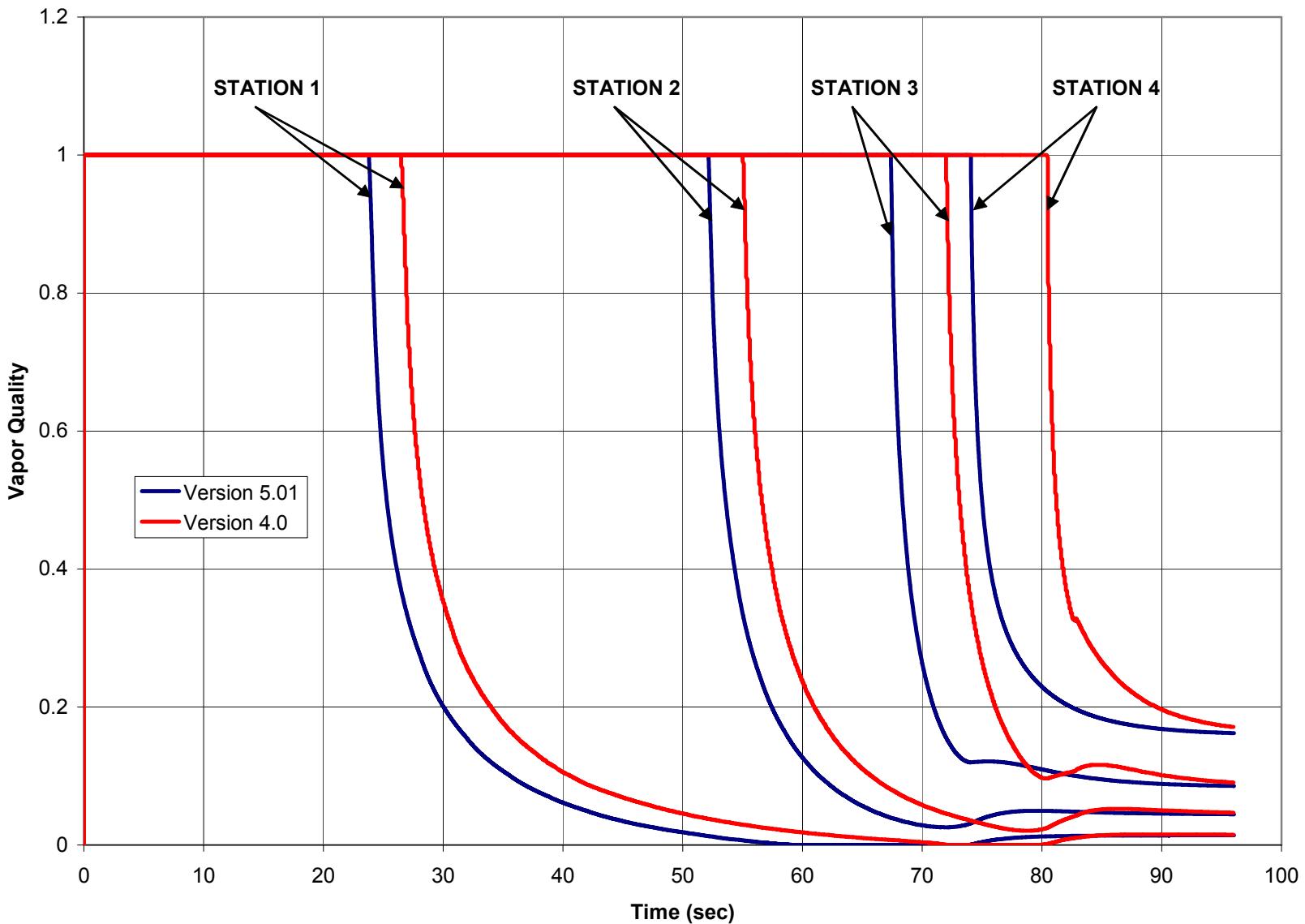
Temperature Comparison



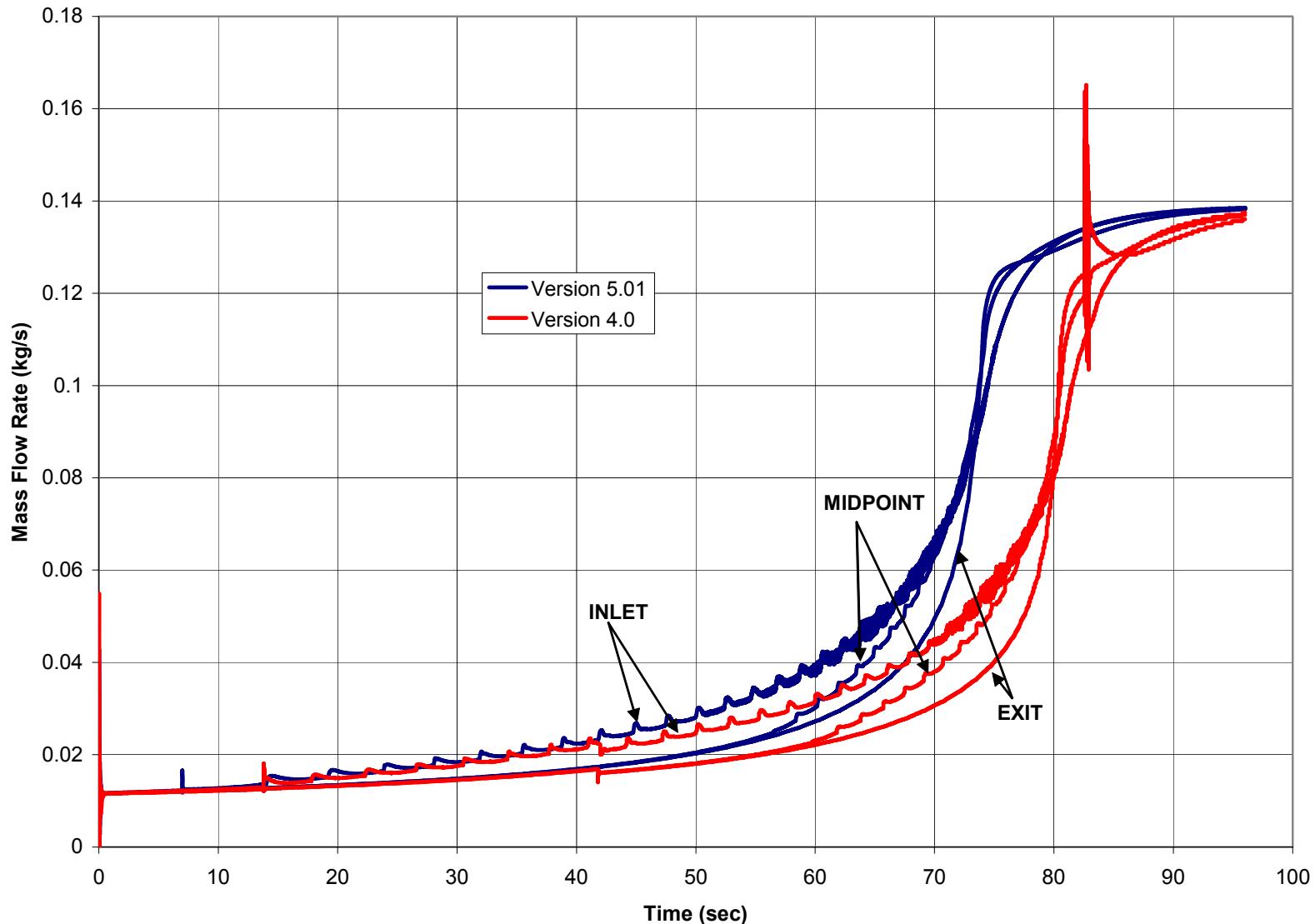
Pressure Prediction



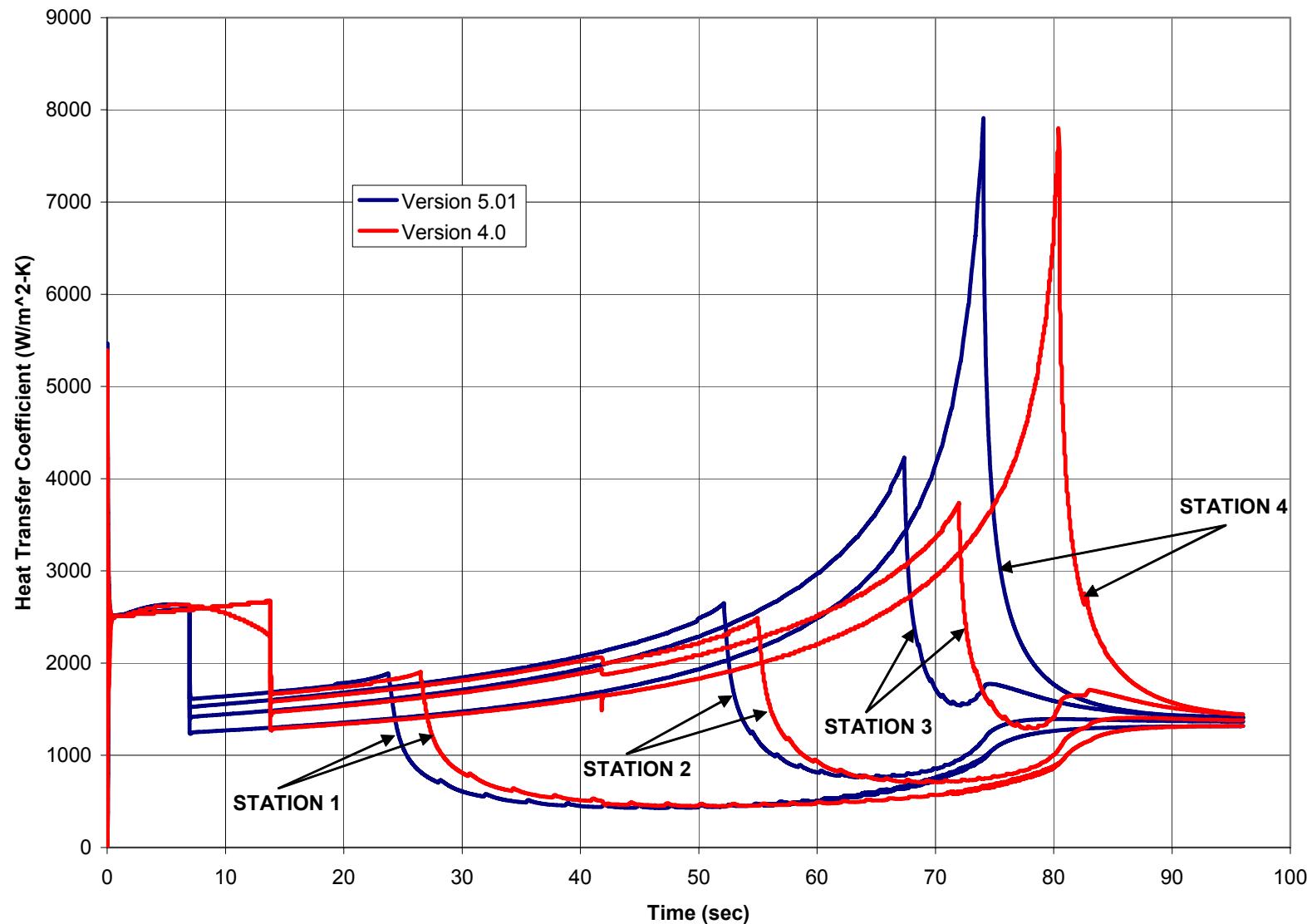
Quality Prediction



Mass Flow Rate Prediction



Heat Transfer Coefficient Prediction



GFSSP

USERS GROUP MEETING

Johnny Maroney
Jacobs Sverdrup

10/26/04



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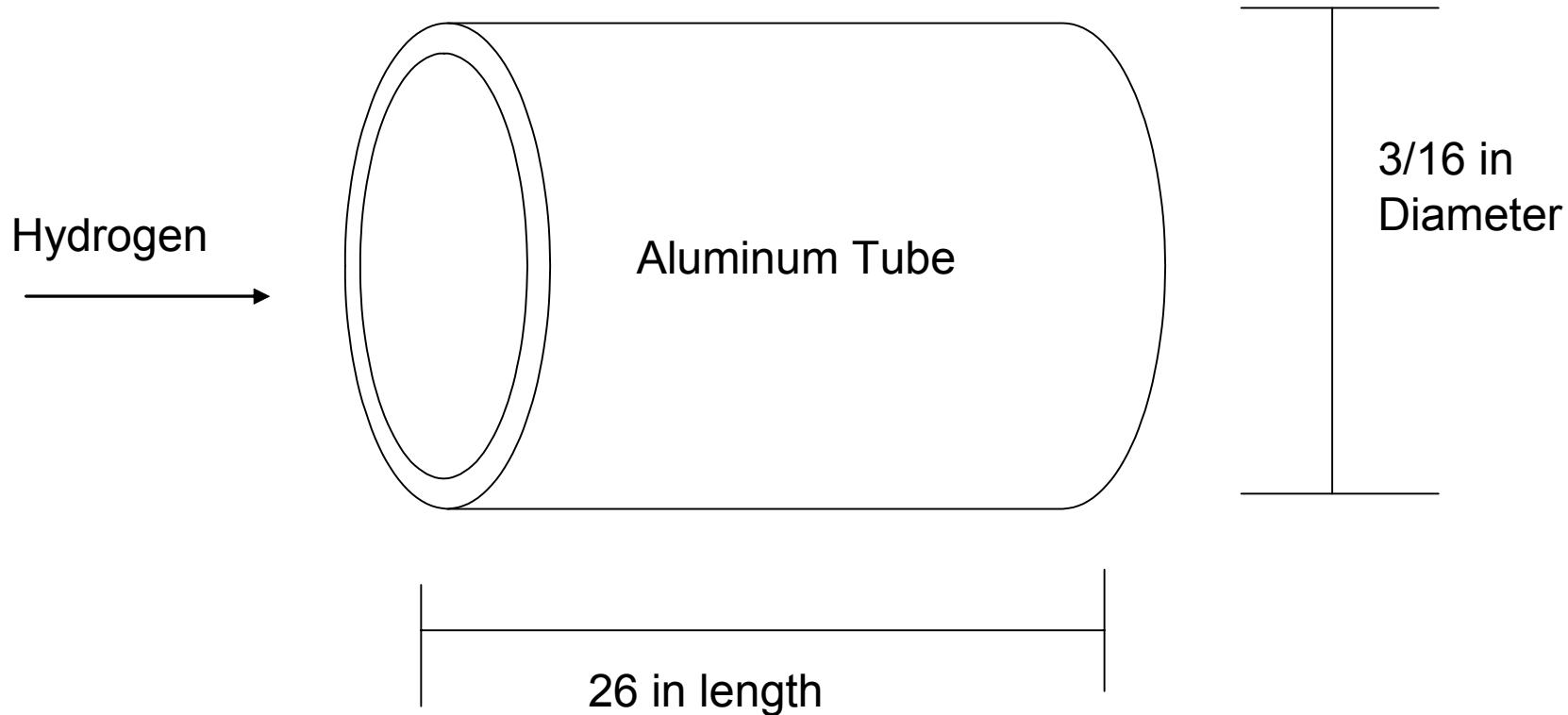
Topics

- Chill down in a small tube
- Micro-Channel
- Stennis LOX Line

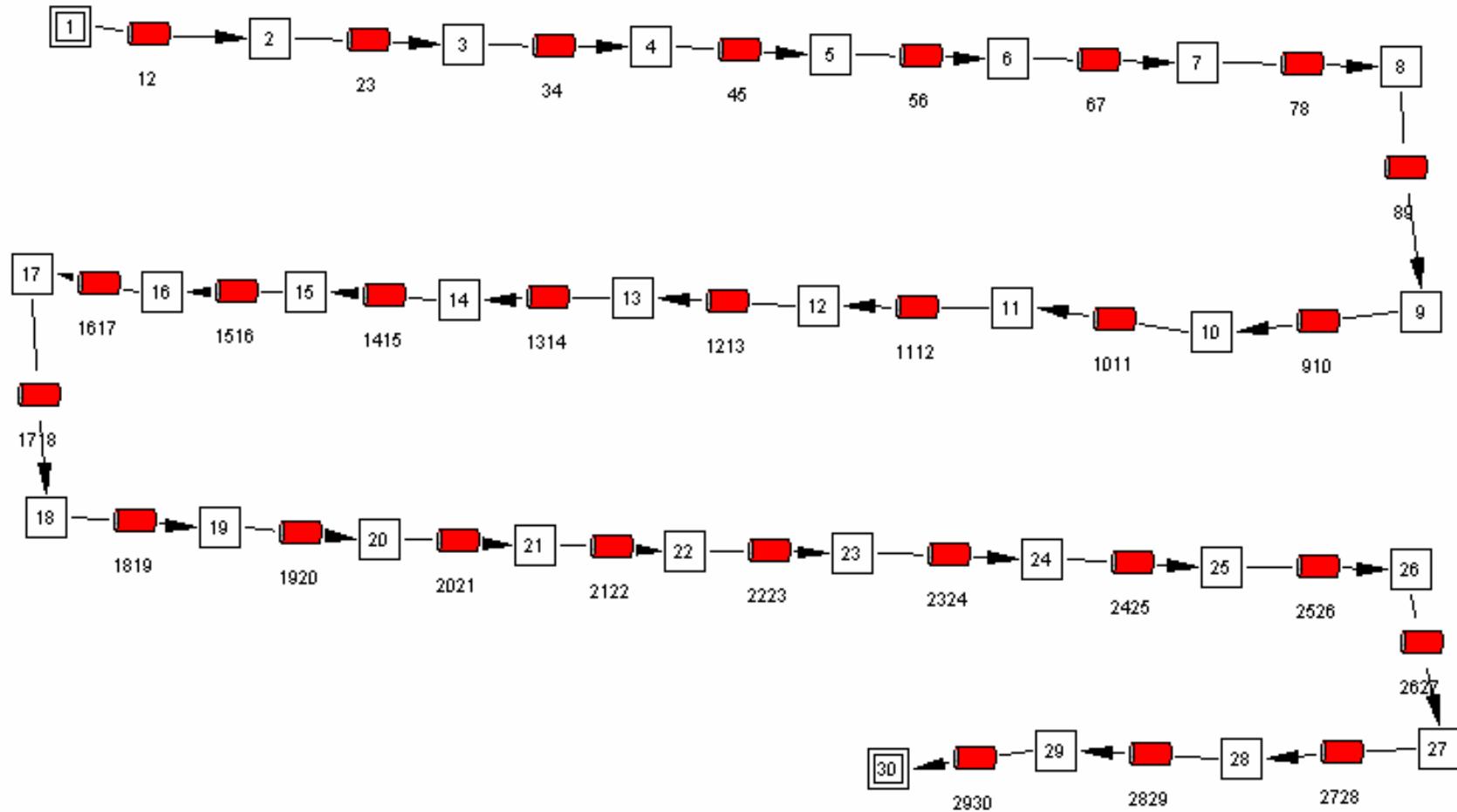
Chill Down in a Small Tube

- Dr. Matthew Cross Doctorial Dissertation
 - Correlated Experimental Data to GFSSP Version 4
- Compared Version 4 to Version 5
 - Heat Transfer in subroutine
 - Conjugate Heat Transfer

Chill Down in a Small Tube



Version 4

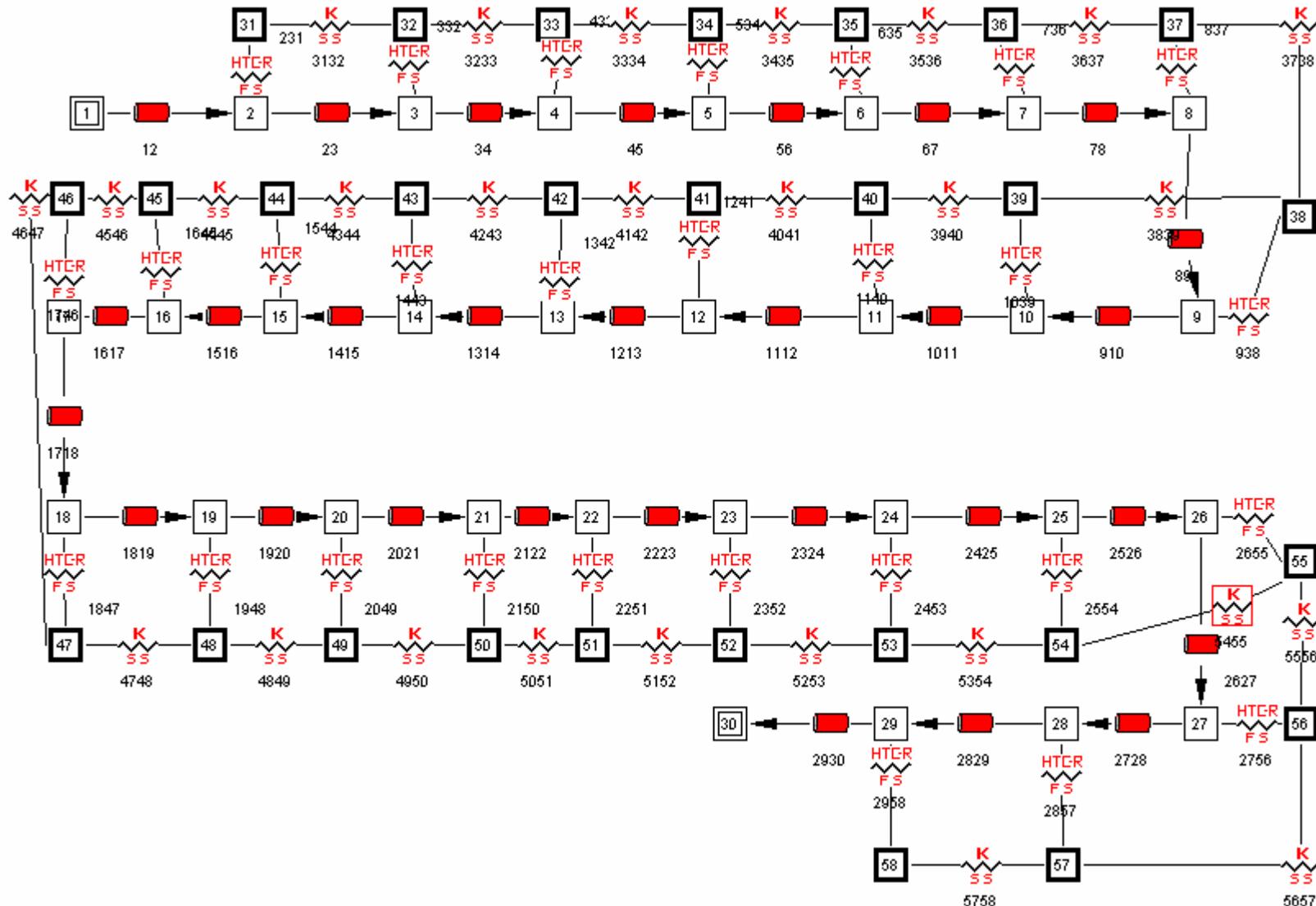


Sverdrup

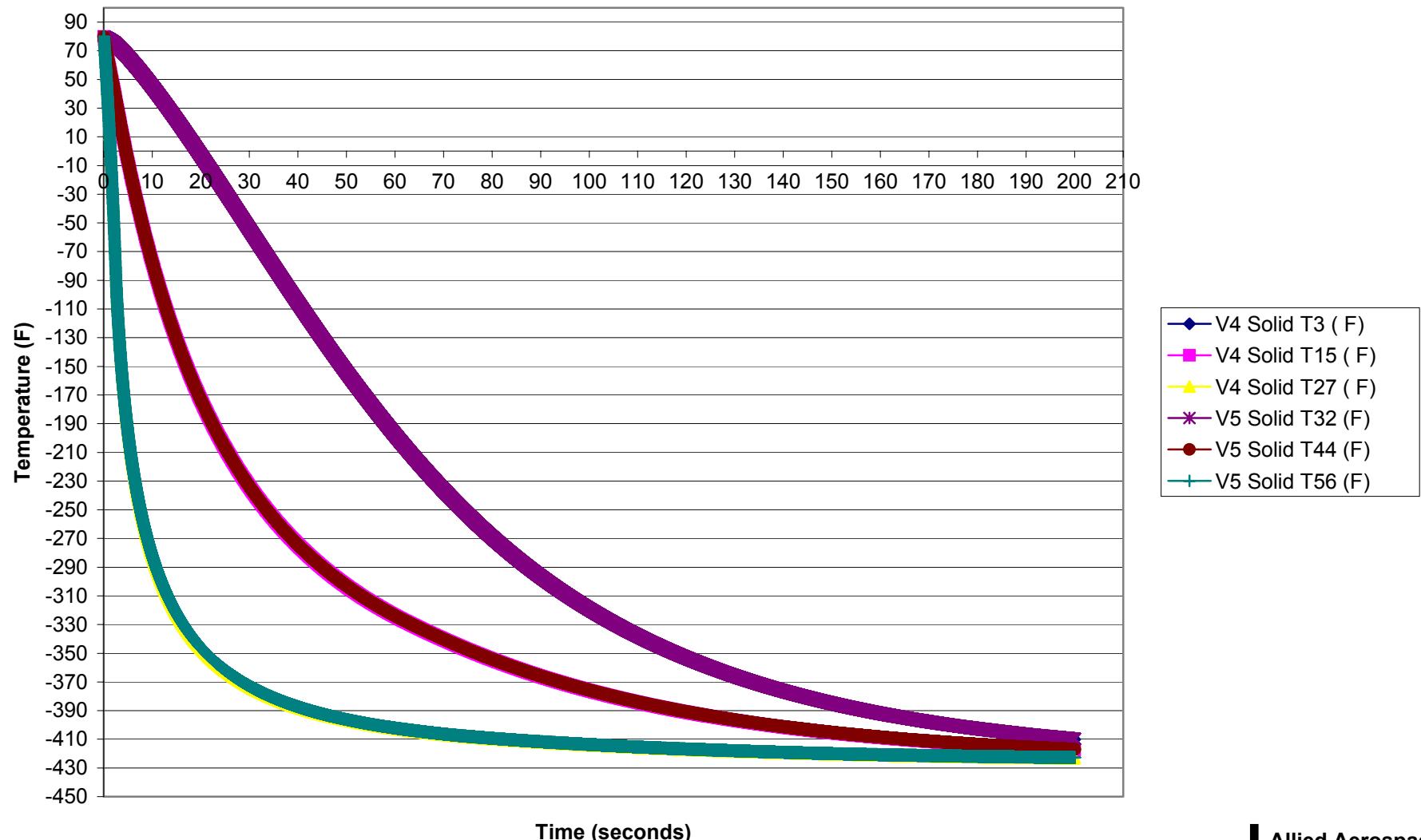
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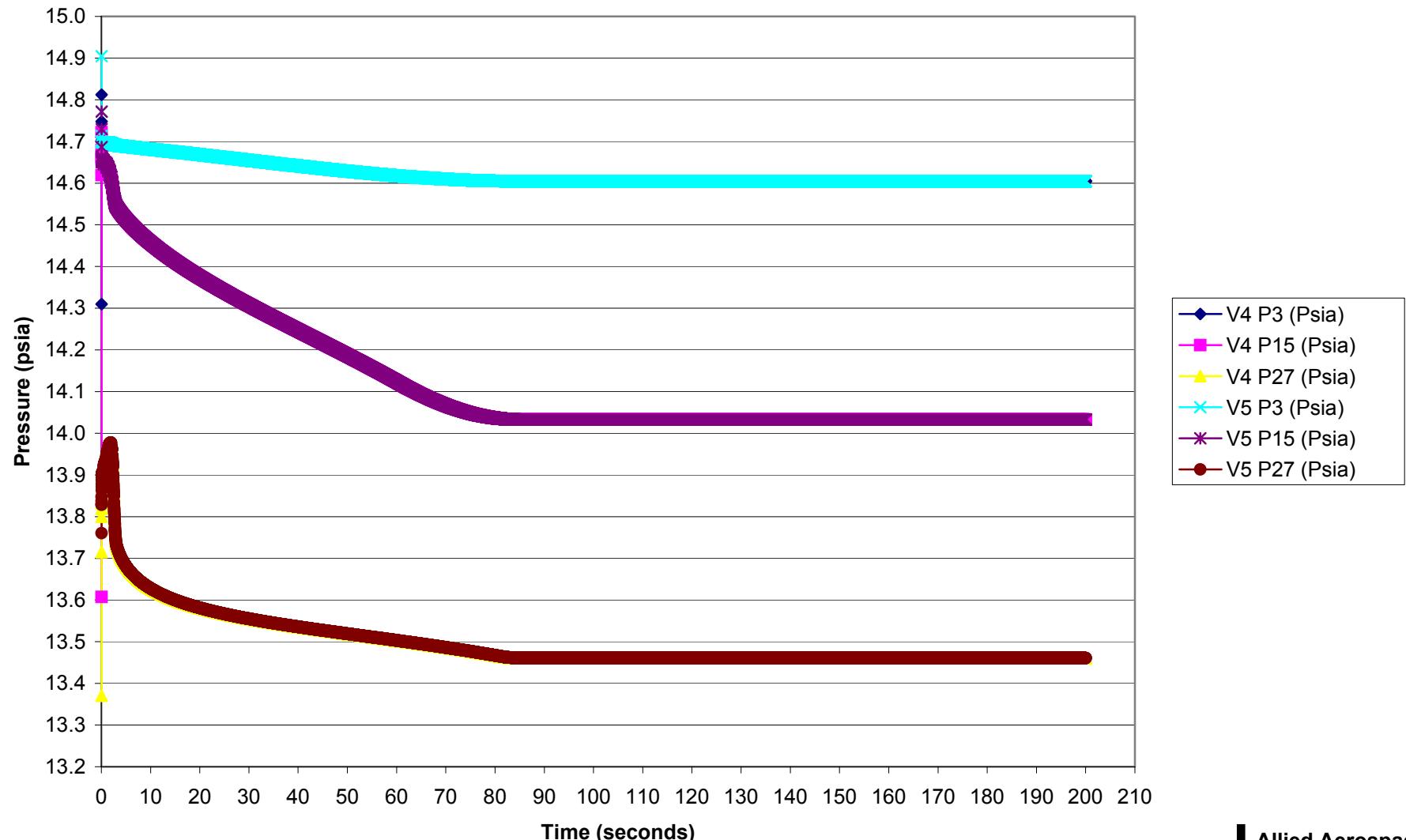
Version 5



V4 & V5, RELH=0, Alok new files, Solid Temperature Comparison



V4 & V5, RELH=0, Alok new files, Pressure Comparison

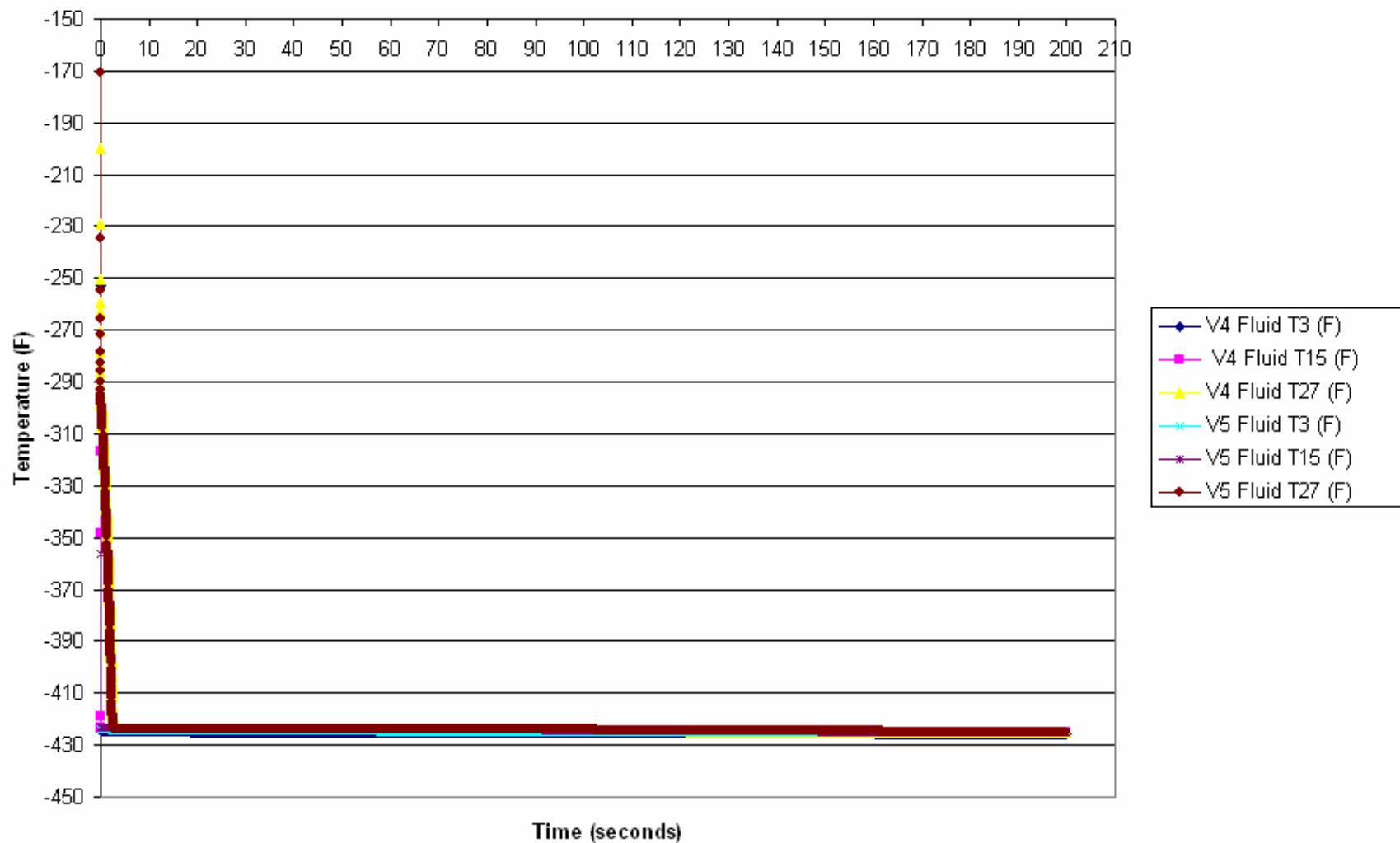


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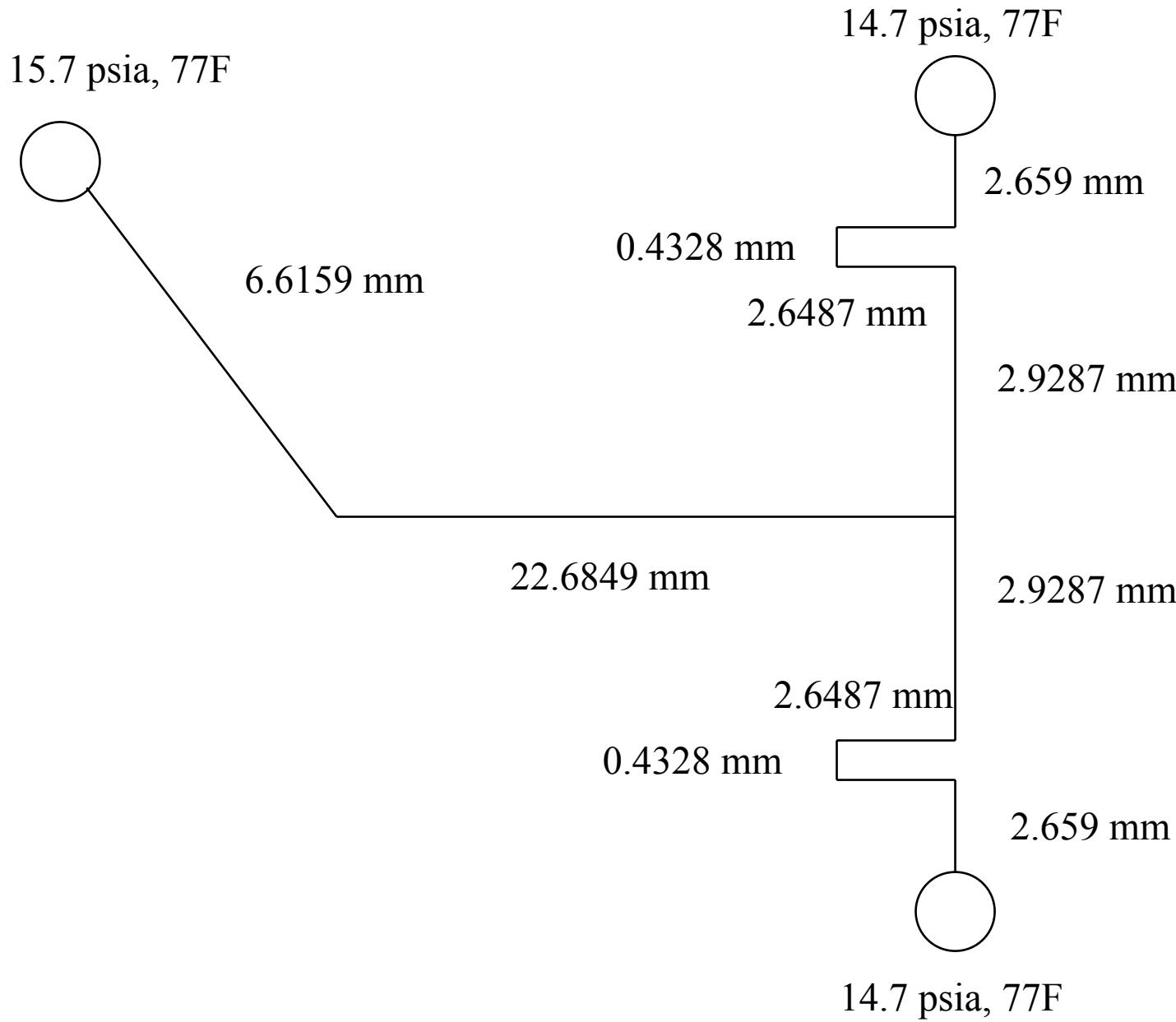
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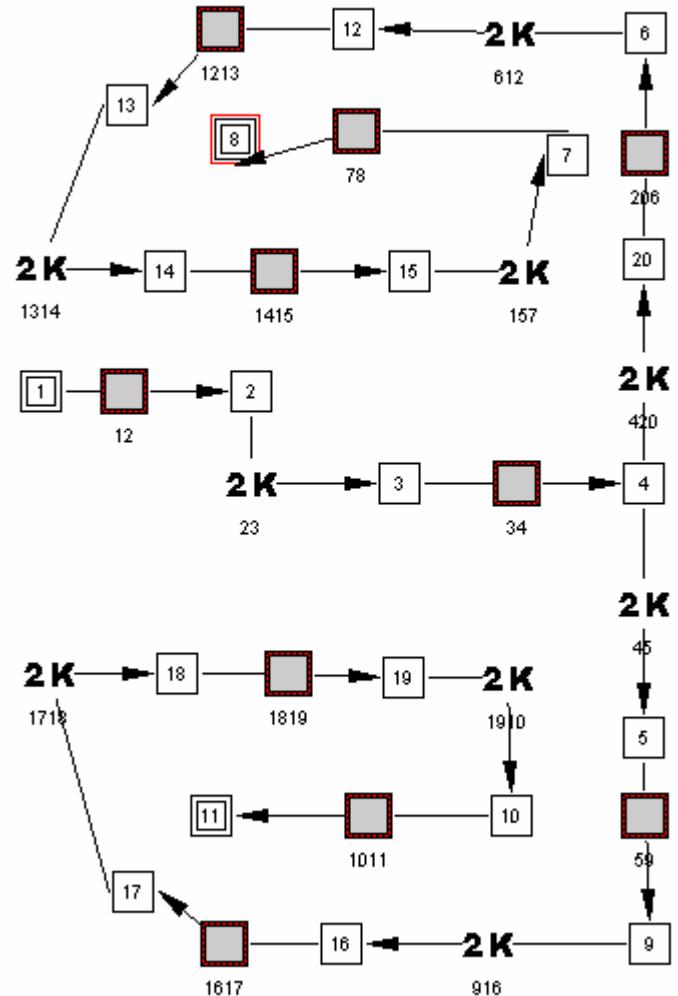
V4 & V5, RELH=0, Alok new files, Fluid Temperature Comparison



Micro-Channel

- Height = 0.000383 inches, width = 0.00238 inches
- 45.5 mm (1.8 inches) total piping
- Rectangular ducts
- Water
- Steady State





Nodes	Pressure (psi)	Temperature (F)	Density (lbm/ft^3)		
1	15.7	77		Boundary Node	
2	15.51	77	62.29		
3	15.51	77	62.29		
4	14.86	77	62.3		
20	14.86	77	62.26		
6	14.82	77	62.3		
12	14.82	77	62.3		
13	14.78	77	62.3		
14	14.78	77	62.3		
15	14.74	77	62.3		
7	14.74	77	62.3		
8	14.7	77		Boundary Node	
5	14.86	77	62.3		
9	14.82	77	62.3		
16	14.82	77	62.3		
17	14.78	77	62.3		
18	14.78	77	62.3		
19	14.74	77	62.3		
10	14.74	77	62.3		
11	14.7	77		Boundary Node	

Branches	Delp (psi)	Flow Rate (lbm/sec)	Velocity (ft/sec)	Reynolds Number	
12	0.189	3.85E-09	0.0102	0.0911	Rectangular Duct
23	0.00144	3.85E-09	0.00839	0.0825	45 degree elbow
34	0.649	3.85E-09	0.0102	0.0911	Rectangular Duct
420	0.00743	1.92E-09	0.00419	0.0412	Tee section
206	0.0419	1.92E-09	0.00513	0.0455	Rectangular Duct
612	0.00113	1.92E-09	0.00419	0.0412	90 degree elbow
1213	0.0378	1.92E-09	0.00512	0.0455	Rectangular Duct
1314	0.00142	1.92E-09	0.00419	0.0412	180 degree elbow
1415	0.0378	1.92E-09	0.00512	0.0455	Rectangular Duct
157	0.00113	1.92E-09	0.00419	0.0412	90 degree elbow
78	0.038	1.92E-09	0.00512	0.0455	Rectangular Duct
45	0.00746	1.92E-09	0.00419	0.0412	Tee section
59	0.042	1.92E-09	0.00512	0.0456	Rectangular Duct
916	0.00113	1.92E-09	0.00419	0.0412	90 degree elbow
1617	0.0379	1.92E-09	0.00512	0.0456	Rectangular Duct
1718	0.00142	1.92E-09	0.00419	0.0412	180 degree elbow
1819	0.0379	1.92E-09	0.00512	0.0456	Rectangular Duct
1910	0.00113	1.92E-09	0.00419	0.0412	90 degree elbow
1011	0.038	1.92E-09	0.00512	0.0456	Rectangular Duct



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RS-84 Subscale Preburner LOX

- Stennis
- Varying Elevations
- Control Valves (% open/closed)
- Inlet at 7210 psia, -281.69F
- Outlet at 6850 psia, -276.1F
- BPV opens at 0.2 seconds, closes at 14.8 seconds
- Valve opens at 4.0 seconds, closes at 12.8 seconds

LOX Run Line Section Identification for K factors

6" pipe ID = 4.209"

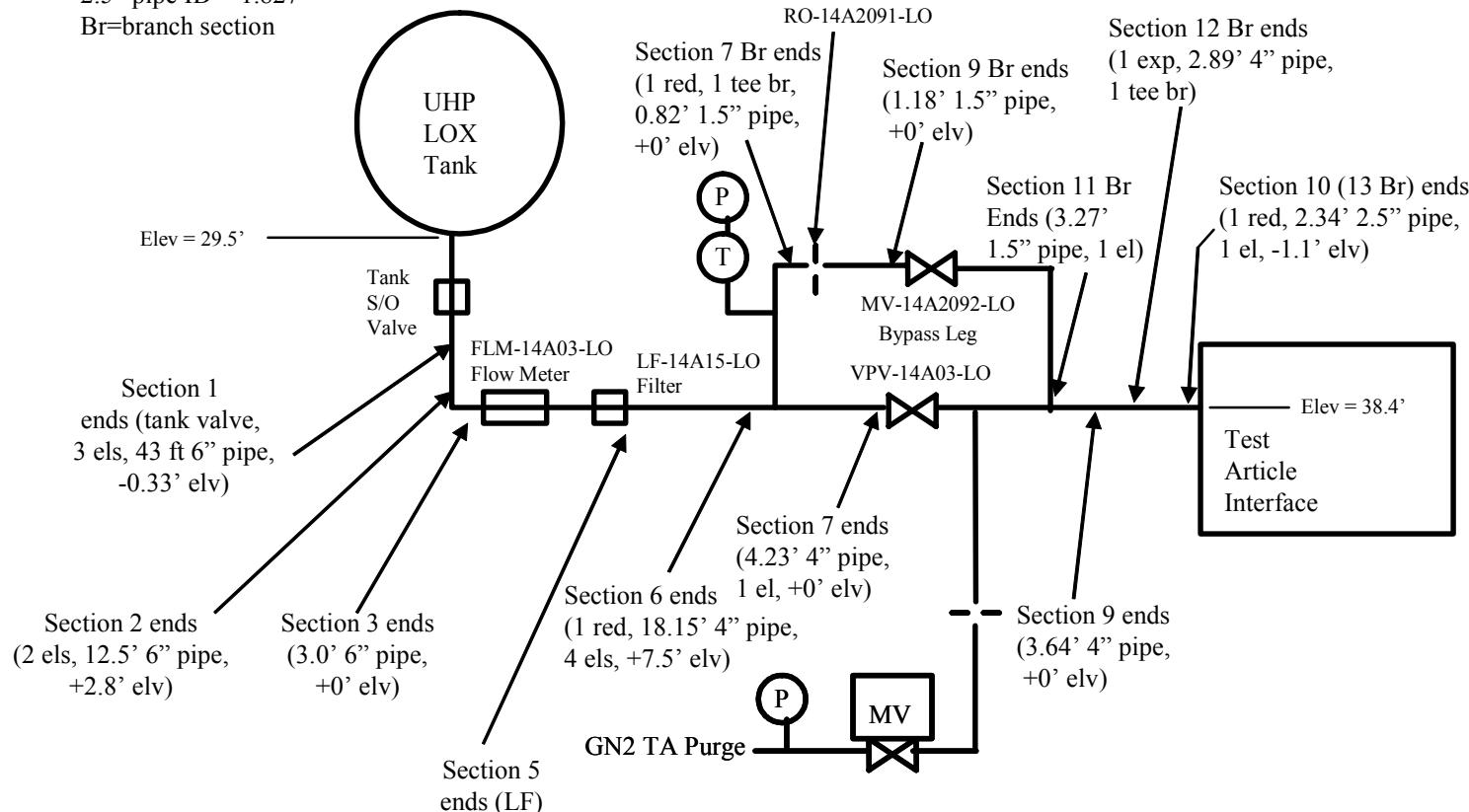
4" pipe ID = 2.86"

4" monel clad pipe ID = 2.61"

1.5" pipe ID = 1.1"

2.5" pipe ID = 1.827"

Br=branch section



Height difference between Tank discharge and Test Article Interface = +8.9'

Volume downstream of MOV VPV-14A03-LO (excluding bypass)= 378.6 cubic inches

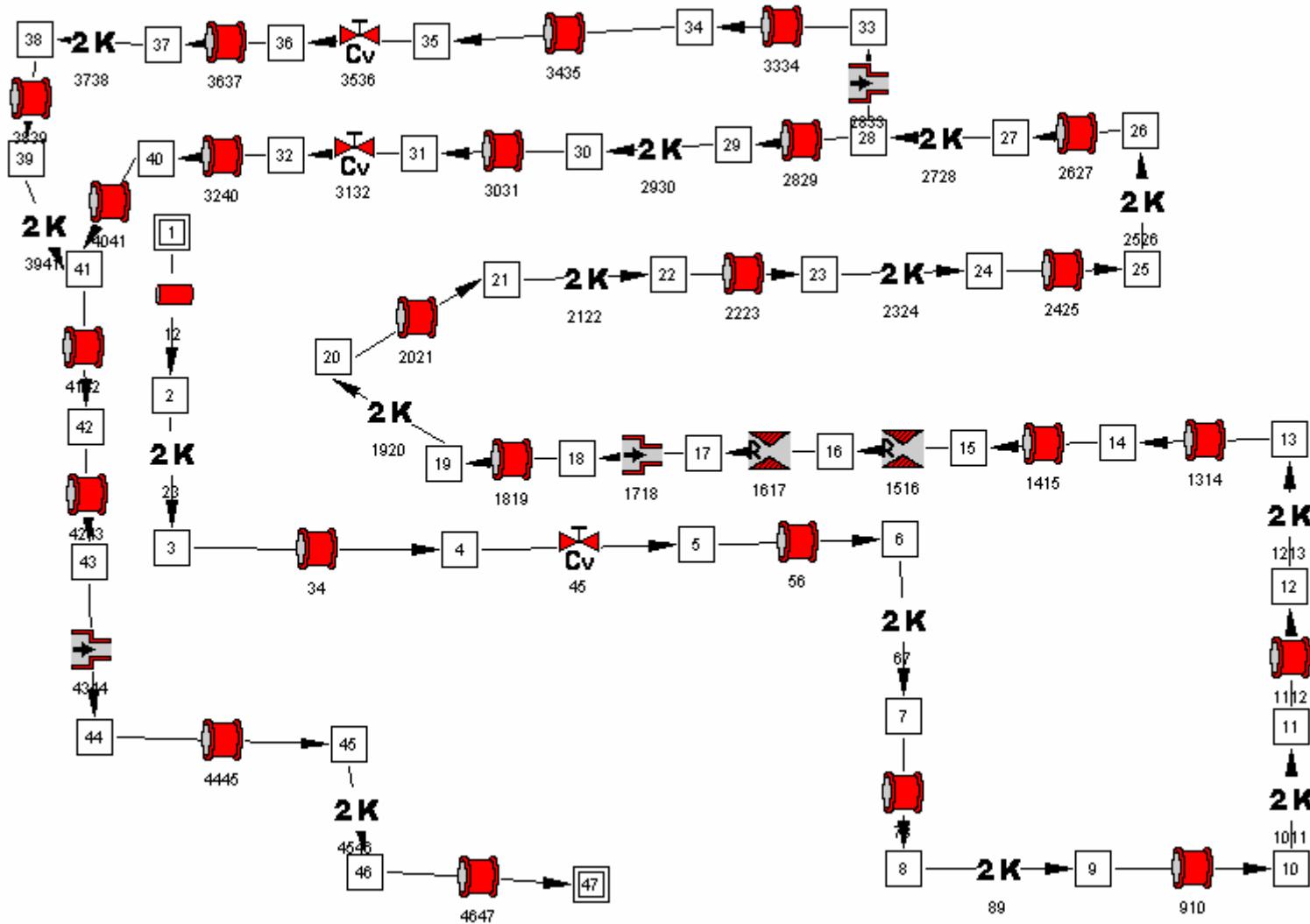
Volume downstream of MV-14A2092-LO to main line tie-in = 38.4 cubic inches



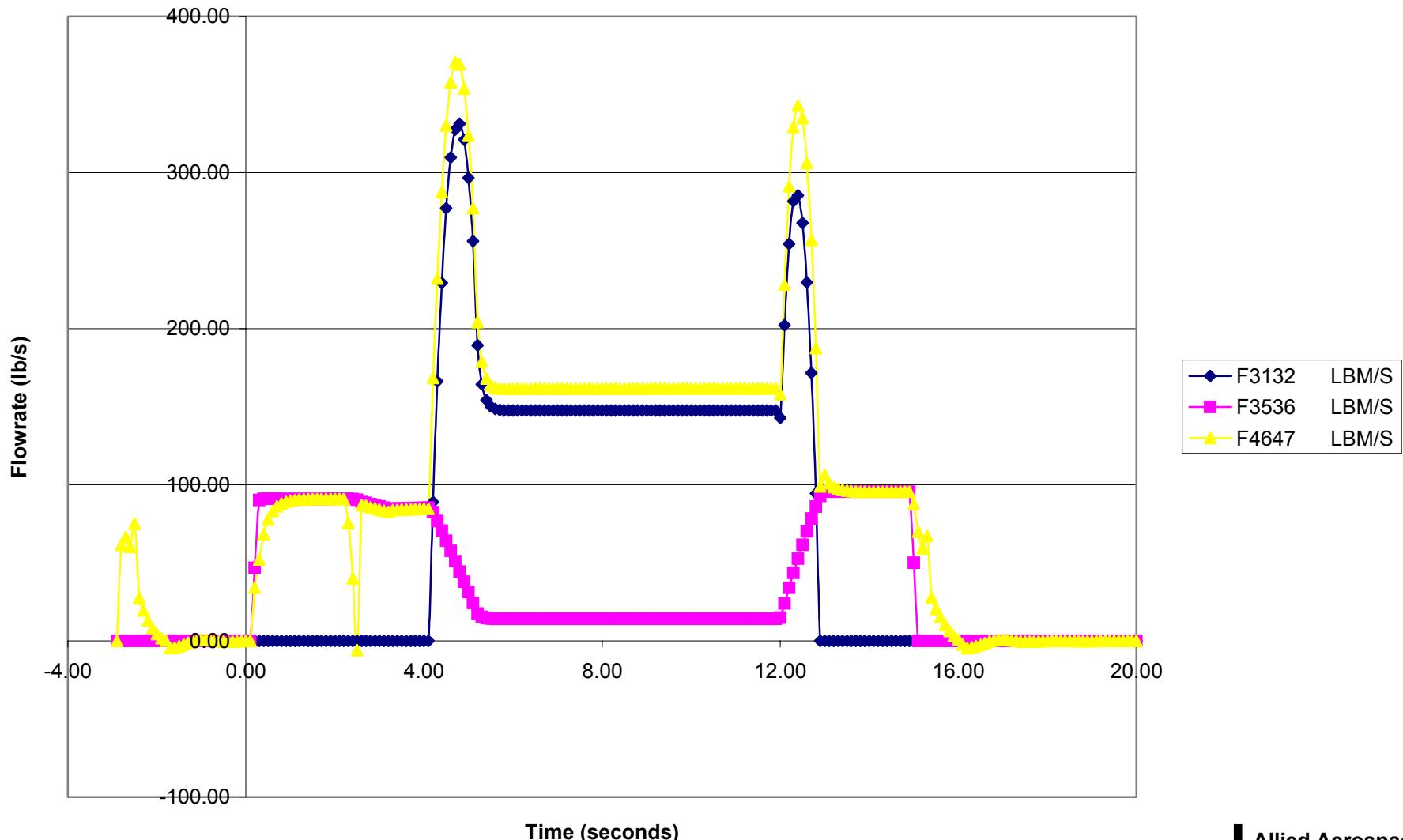
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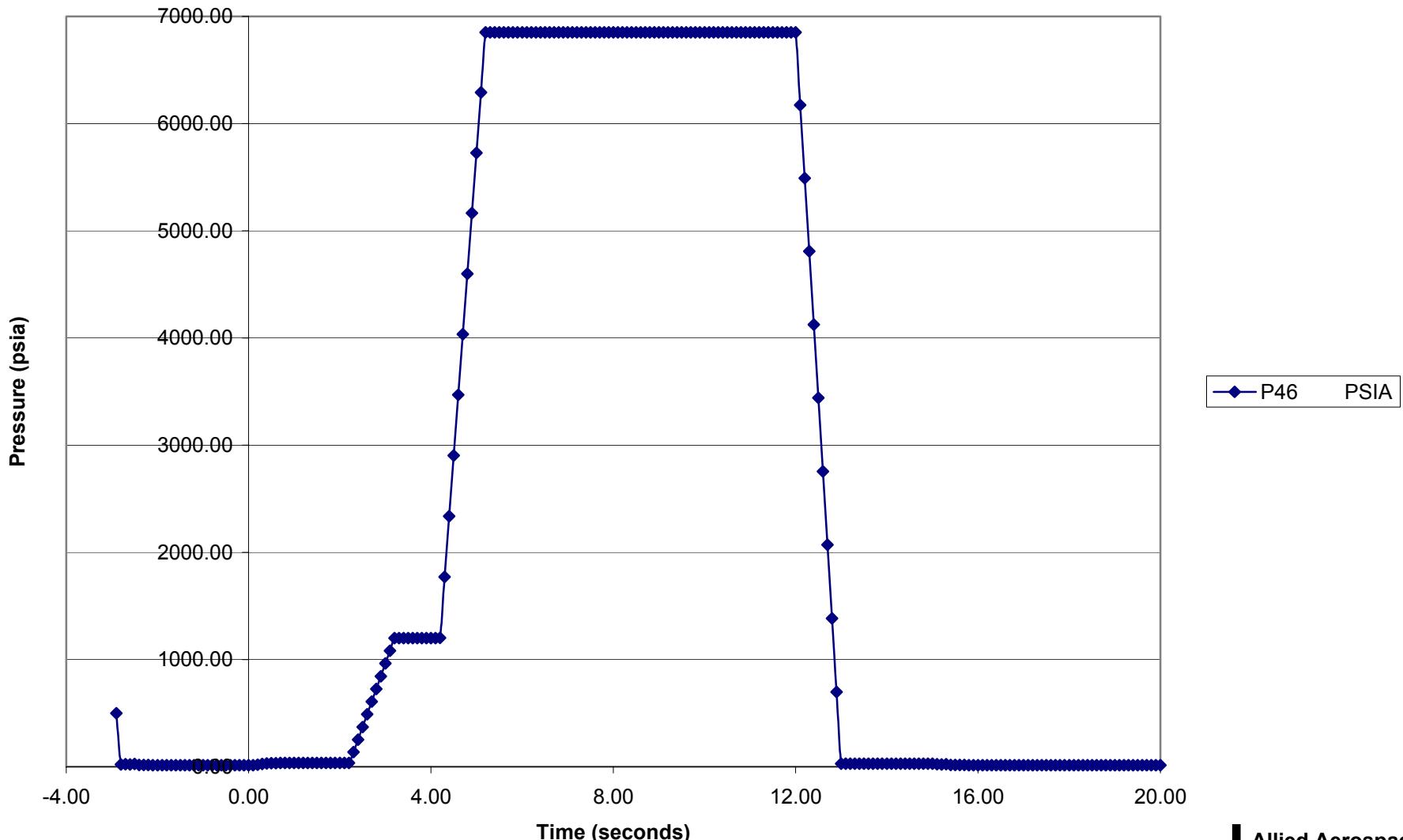
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LOX Flowrate history for Main and Bypass Line and Test Article, Time Step = 0.1 Seconds



LOX Pressure History at Test Article, Time Step = 0.1 Seconds

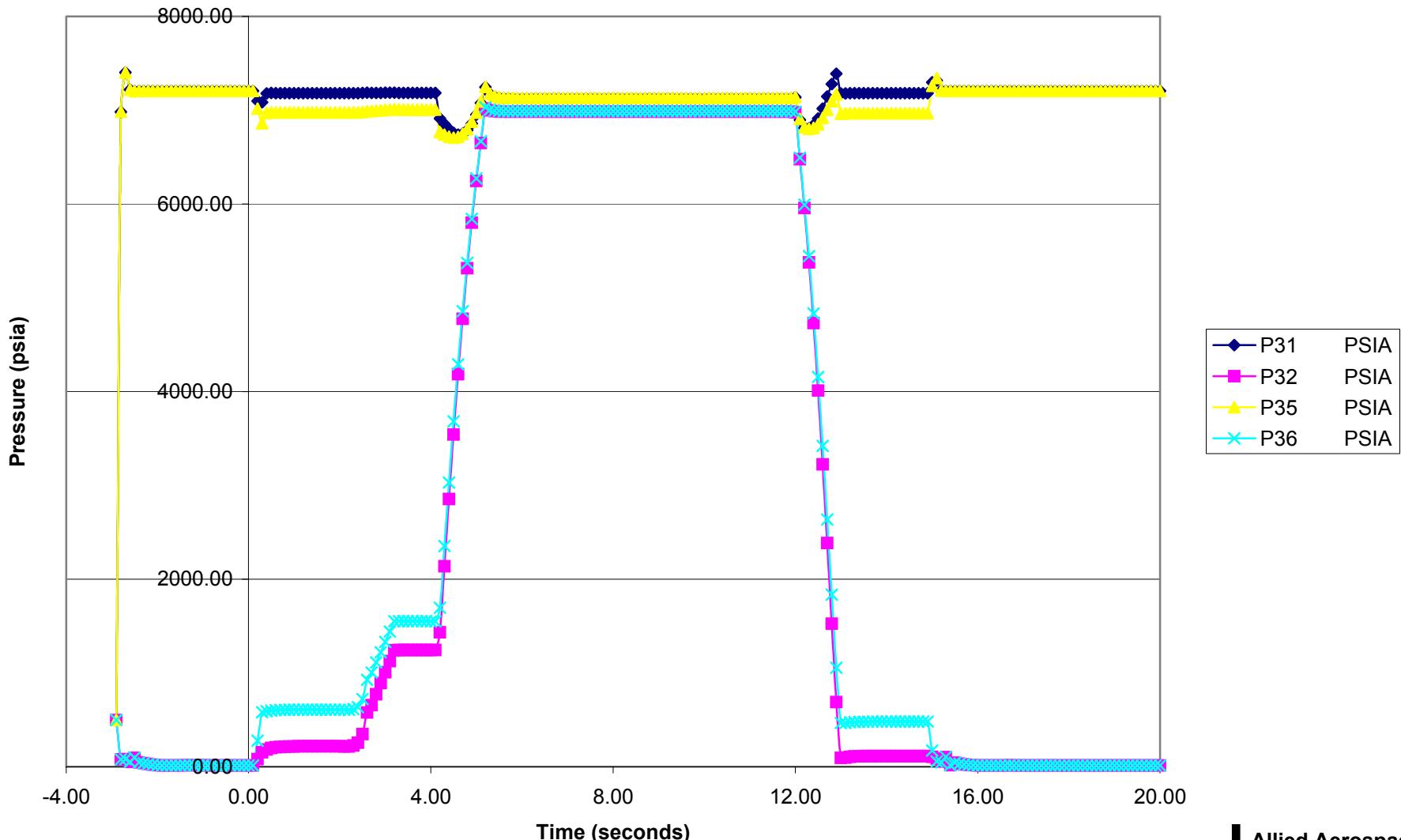


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LOX Pressure History for Main and Bypass Valve, Time Step = 0.1 Seconds



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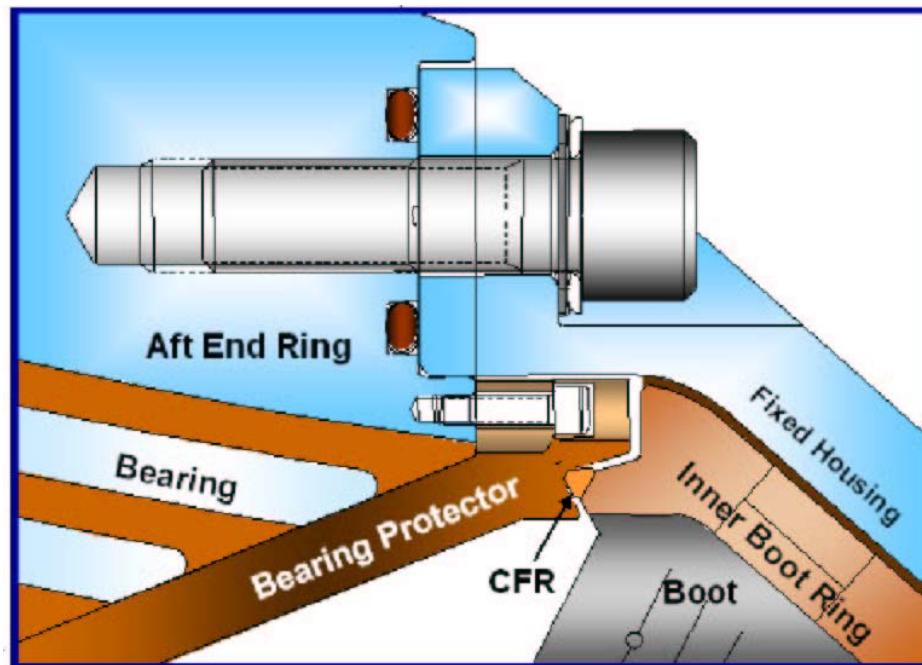
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Introduction

- Topics
 - Rapid Pressurization of Solid Rocket Motor (SRM) Field Joint
 - Nitrogen Cryo-Pumping Into Thermal Protection Protection System (TPS) Foam Voids & Subsequent Ejection

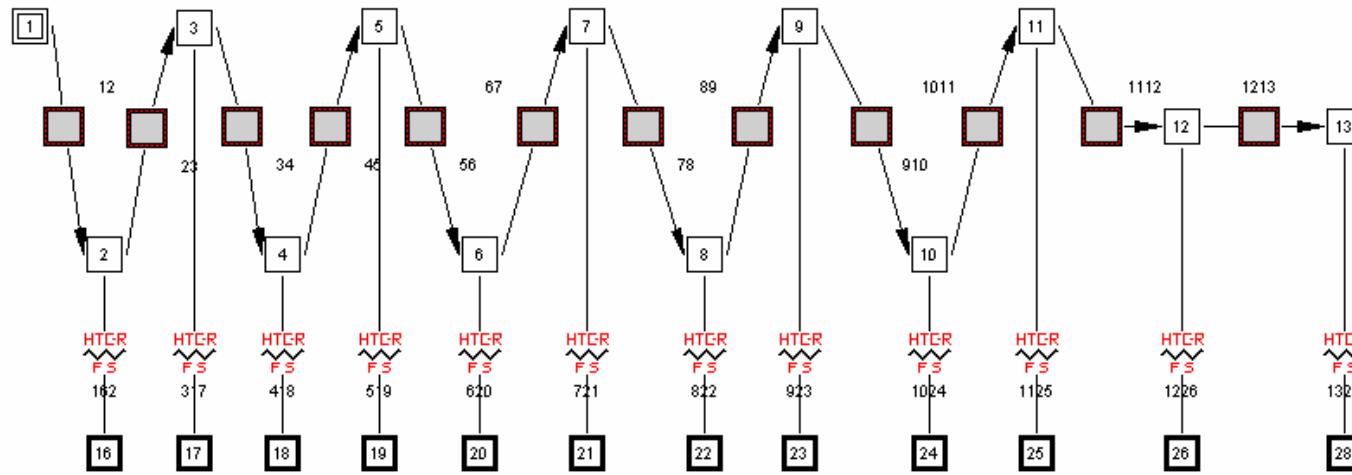
Field Joint Pressurization

- Problem Description
 - Channel Is Pressurized From 12.2 psia and 60 °F to °F to 900 psia and 2300 °F Within 1 Second
 - Highly Transient Fluid Flow Within and Heat Transfer to Surrounding Structure



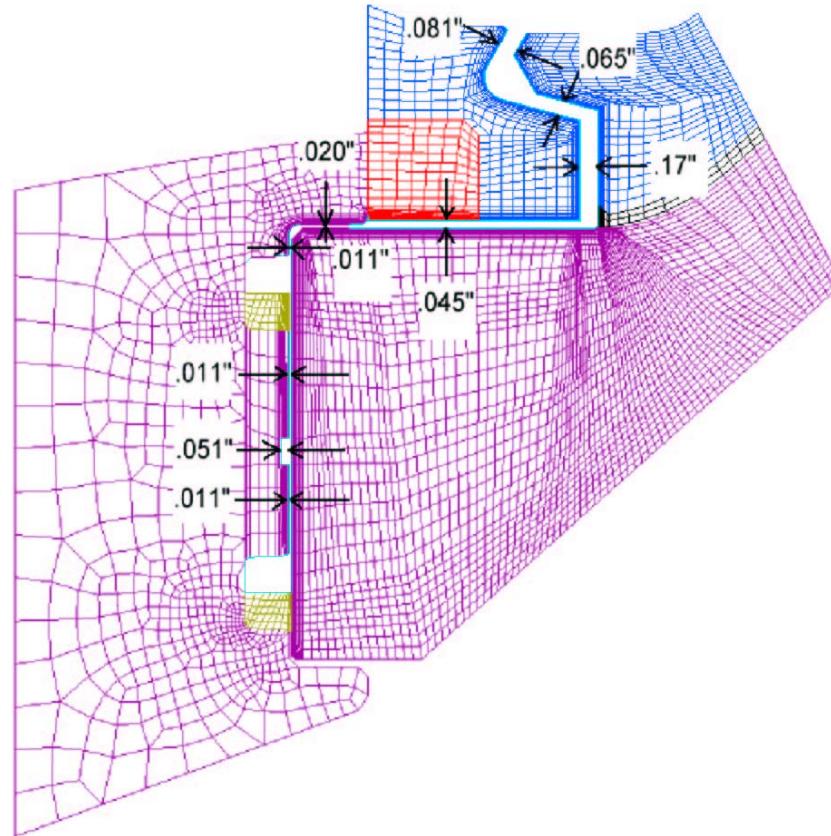
Field Joint Pressurization

- GFSSP Model Description
 - Single Boundary Node Represents Flow Inlet
 - Last Node Represents Primary O-Ring Gland
 - Nodes/Branches In Between Represent Flow Channel
 - Conjugate Heat Transfer To Solid Nodes



Field Joint Pressurization

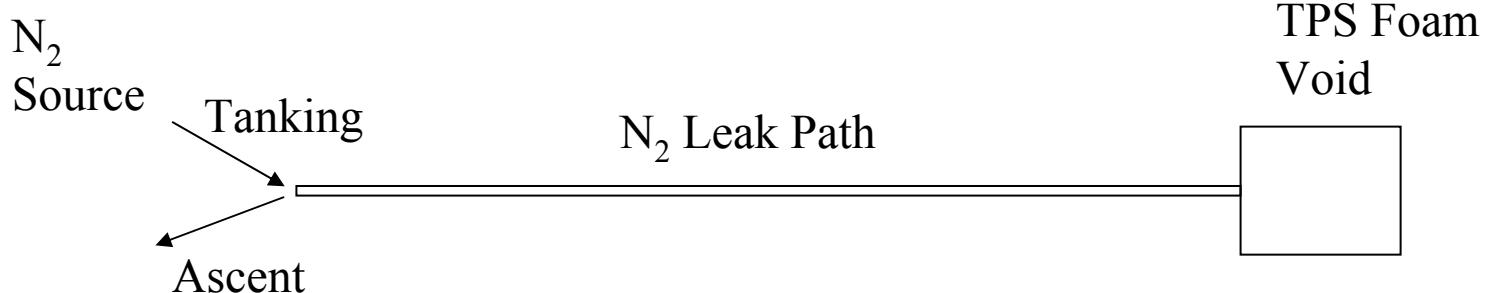
- Future Efforts
 - Integrate GFSSP With Solid Structure Heat Transfer Code For Advanced Conjugate Modeling Modeling



N_2 Cryo-Pumping & Ejection

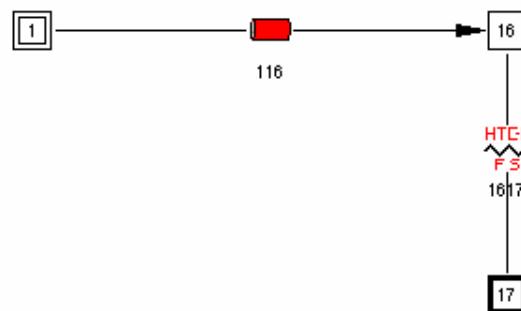
- Problem Description

- Voids Unintentionally Produced During TPS Application
- Void/Channel Initially Filled With GN_2
- Foam Around Void Cools To LH_2 Temp. (-423 °F) During Shuttle Tanking
- Cryo-Pumping Draws N_2 Into Void
- N_2 Is Ejected From Void Due To Subsequent TPS Heating During Shuttle Ascent



N_2 Cryo-Pumping & Ejection

- GFSSP Model Description
 - For In-Flow, Transient Inlet Conditions For Fluid Provided At Node 1
 - Void Temperature (N_2 & Foam Walls) Approximated As Spatially Uniform At Each Time Step (Tanking & Ascent)
 - Transient Void Temperature Specified By Using Solid Node In Conjunction With Fluid Node and Very Low Resistance Conductor (i.e. Very High h)





SSME Regen. Cooling Problem



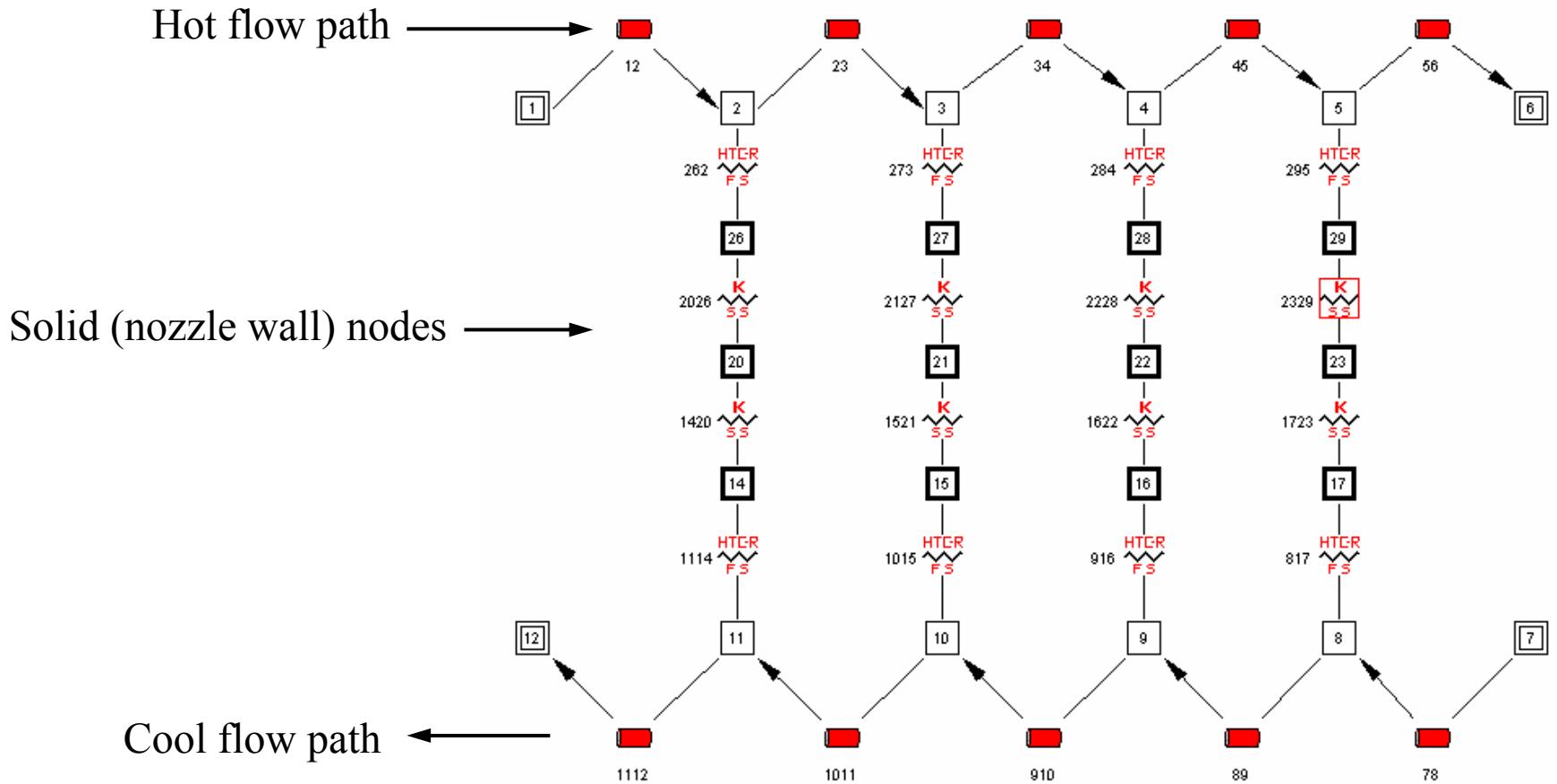
Objective:

- Use GFSSP to model heat transfer between main MCC flow and regenerative cooling flow.

Accomplished:

1. Developed a simple model of heat transfer between two counter flow fluids.
2. Investigated GFSSP's ability to predict flow conditions in a Converging-Diverging nozzle

Basic Heat Exchanger Model

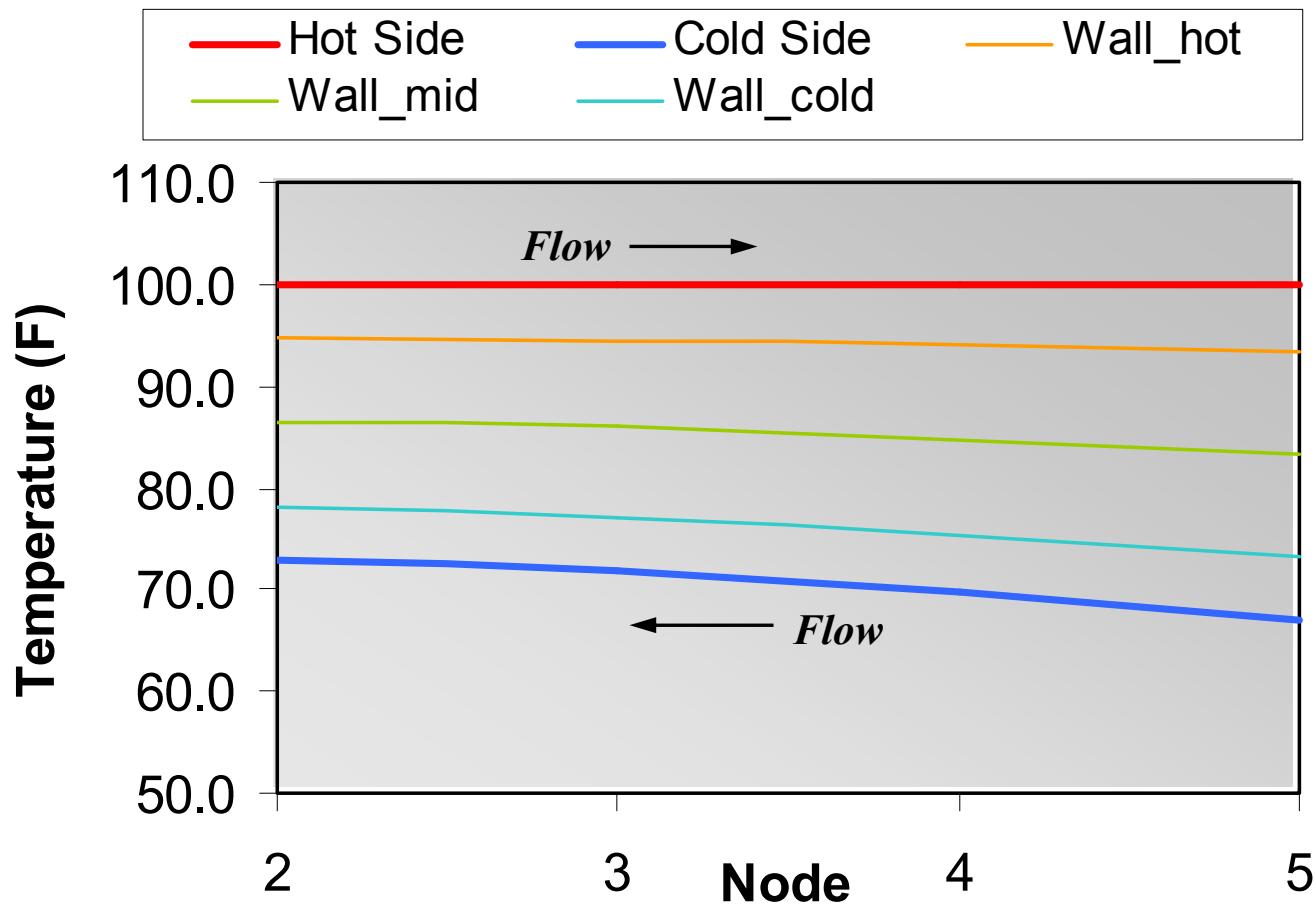


Model geometry (i.e. pipe diameter, wall thickness, etc...) was chosen arbitrarily

Basic Heat Exchanger Model

Temperature distribution in a counter flow heat exchanger

* Working fluid - H_2O





User Subroutine for hg & hc

Equation for Gas side (Bartz):

$$h_g = \left[\frac{0.026}{D_t^{0.2}} \left(\frac{\mu^{0.2} C_p}{\text{Pr}^{0.6}} \right)_{ns} \left(\frac{(p_c)_{ns} g}{c^*} \right)^{0.8} \left(\frac{D_t}{R} \right)^{0.1} \right] \times \left(\frac{A_t}{A} \right)^{0.9} \times \sigma$$

Where, $\sigma = \frac{1}{\left[\frac{1}{2} \frac{T_{wg}}{(T_c)_{ns}} \left(1 + \frac{\gamma - 1}{2} M^2 \right) + \frac{1}{2} \right]^{0.68} \left[1 + \frac{\gamma - 1}{2} M^2 \right]^{0.12}}$

Equation for Coolant Side:

$$h_c = \frac{0.029 C_p \mu^{0.2}}{\text{Pr}^{2/3}} \left(\frac{G^{0.8}}{d^{0.2}} \right) \left(\frac{T_{co}}{T_{wc}} \right)^{0.55}$$



User Subroutine for h_g & h_c



```
C*****
```

```
SUBROUTINE USRHCF(NUMBER,HCF)
```

```
C PURPOSE: PROVIDE HEAT TRANSFER COEFFICIENT
```

```
C*****
```

```
INCLUDE 'COMBLK.FOR'
```

```
C*****
```

```
C Loop to determine throat area and diameter
```

```
areat=10000
```

```
do numbera=2,5
```

```
call indexi(numbera,node,nnodes,ipn)
```

```
call indexud(ipn,node,inode,nint,numbr,namebr,nbr,
```

```
&           ibrn,ibrdnibranch,ibu,ibd)
```

```
if (area(ibu) .LT. areat) then
```

```
    areat = area(ibu)
```

```
endif
```

```
enddo
```

```
Dt = (4.0*areat*144.0/3.141593)**(0.5)
```

```
R = 0.75*Dt
```

```
C*****
```

```
C Call Nozzle Properties
```

```
numberb=1
```

```
call indexi(numberb,node,nnodes,ipnb)
```

```
y = gama(ipnb)
```

```
aMach = emach(ipnb)
```

```
Pns = p(ipnb)*(1+(y-1)/2*aMach**2)**(y/(y-1))
```

```
Tns = TF(ipnb)*(1+(y-1)/2*aMach**2)
```

```
cstar = sqrt(32.2*y*Rnode(ipnb)*Tns)/
```

```
&           (y*sqrt((2/(y+1))**((y+1)/(y-1))))
```

```
Cp = Cpnnode(ipnb)
```

```
vis = emu(ipnb)/12.0
```

```
Prl = Pr(ipnb)
```

```
g = 32.2
```



User Subroutine for h_g & h_c

C Call index variables and determine heat transfer coefficient

Do numberc = 2,5

call indexi(numberc,node,nnodes,ipn)

call indexud(ipn,node,inode,nint,numbr,namebr,nbr,ibrun,ibrdn,ibranch,ibu,ibd)

numberd = numberc + 24

call indexs(numberd,nodesl,nsolidx,ipsn)

bmach = sqrt(2/(y-1)*((Pns/P(ipn))((y-1)/y)-1))**

sigma = 1/((0.5*(Ts(ipsn)/Tns)*(1+(y-1)/2*bmach2)+0.5)**(0.68)*(1+(y-1)/2*bmach**2)**(0.12))**

HCF = 0.026/Dt(0.2)*(vis**0.2)*Cp/PrI**0.6)*(Pns*g/cstar)**

& **0.8)*(Dt/R)0.1)*(areat/area(ibu))**0.9)*sigma**

Enddo

Do numbere = 8,11

call indexi(numbere,node,nnodes,ipn)

call indexud(ipn,node,inode,nint,numbr,namebr,nbr,ibrun,ibrdn,ibranch,ibu,ibd)

numberf = numbere + 6

call indexs(numberf,nodesl,nsolidx,ipsn)

Gdot = flowr(ibu)/area(ibu)/144.

dia = (4.0*area(ibu)*144.0/3.141593)**0.5

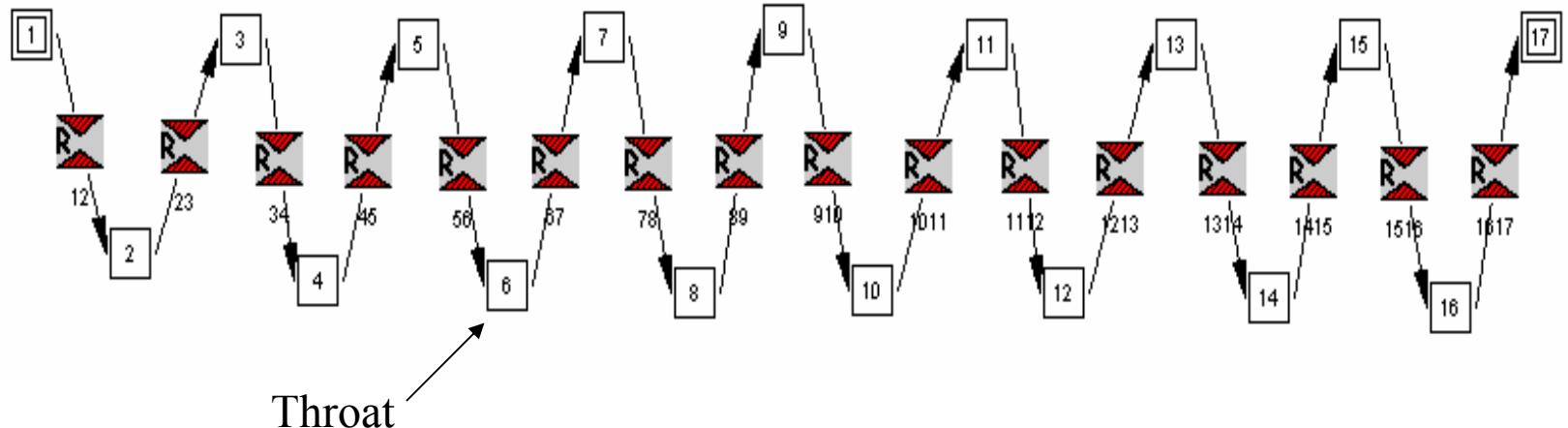
HCF = 0.029*cnode(ipn)*vis0.2/Pr(ipn)**(2/3)*Gdot**0.8)/dia**0.2)*(Tf(ipn)/Ts(ipsn))**0.55**

Enddo

RETURN

END

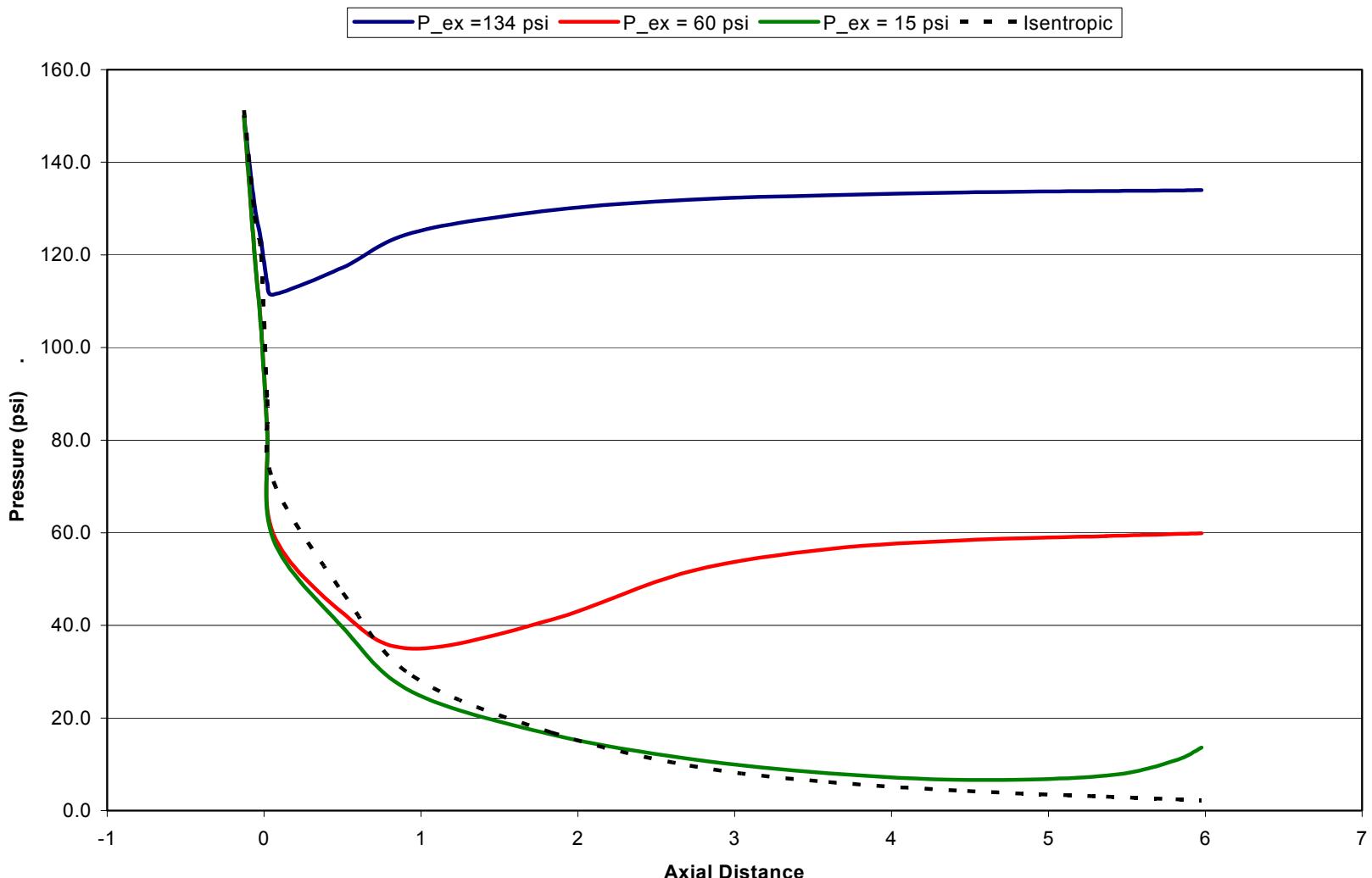
C*****



- Tutorial 2 in GFSSP Course Charts
- Working fluid – H_2O (steam)
- Inlet Pressure - 150 psi



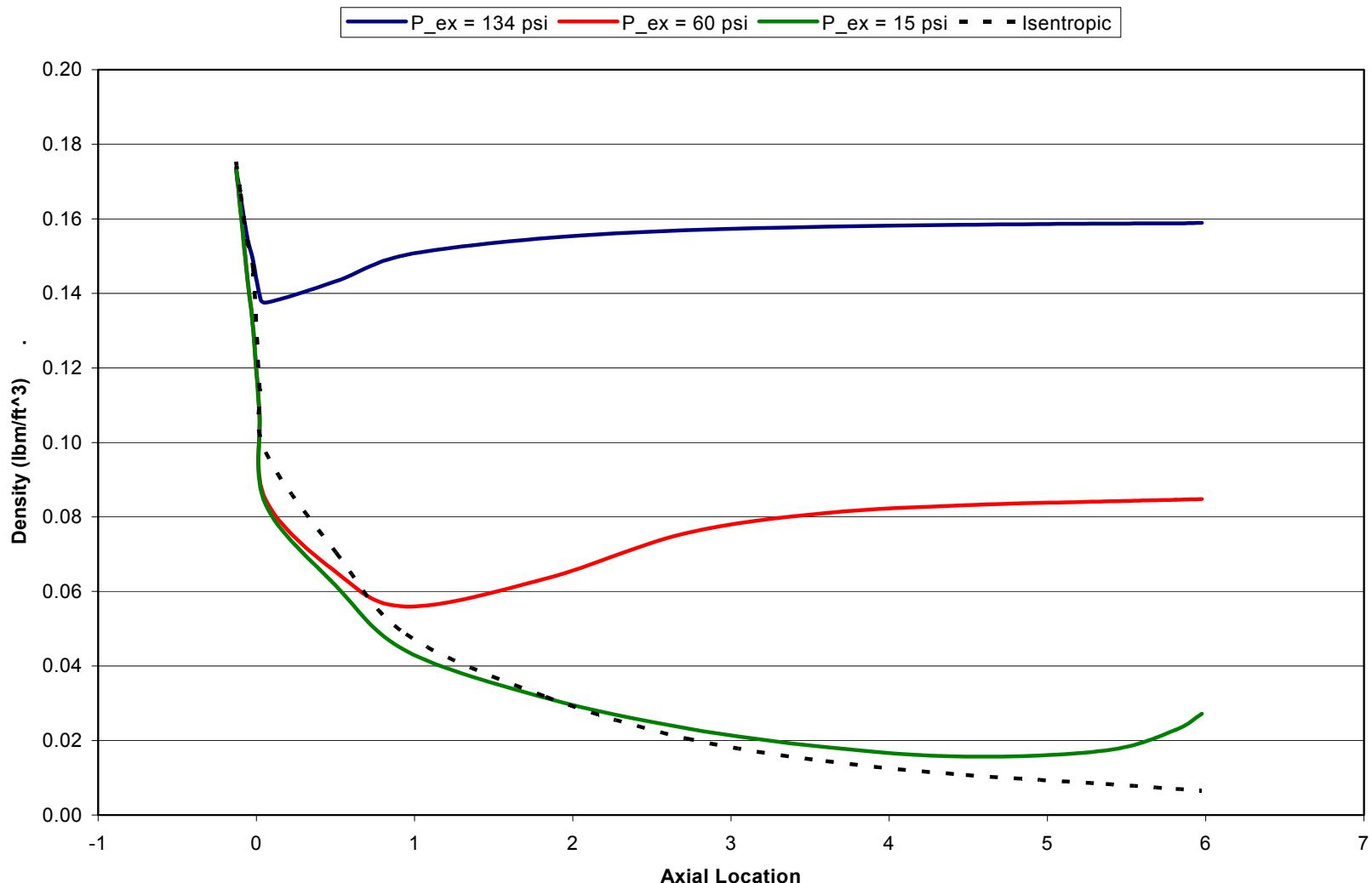
GFSSP Modeling – CD Nozzle Investigation



Pressure vs. Axial Location



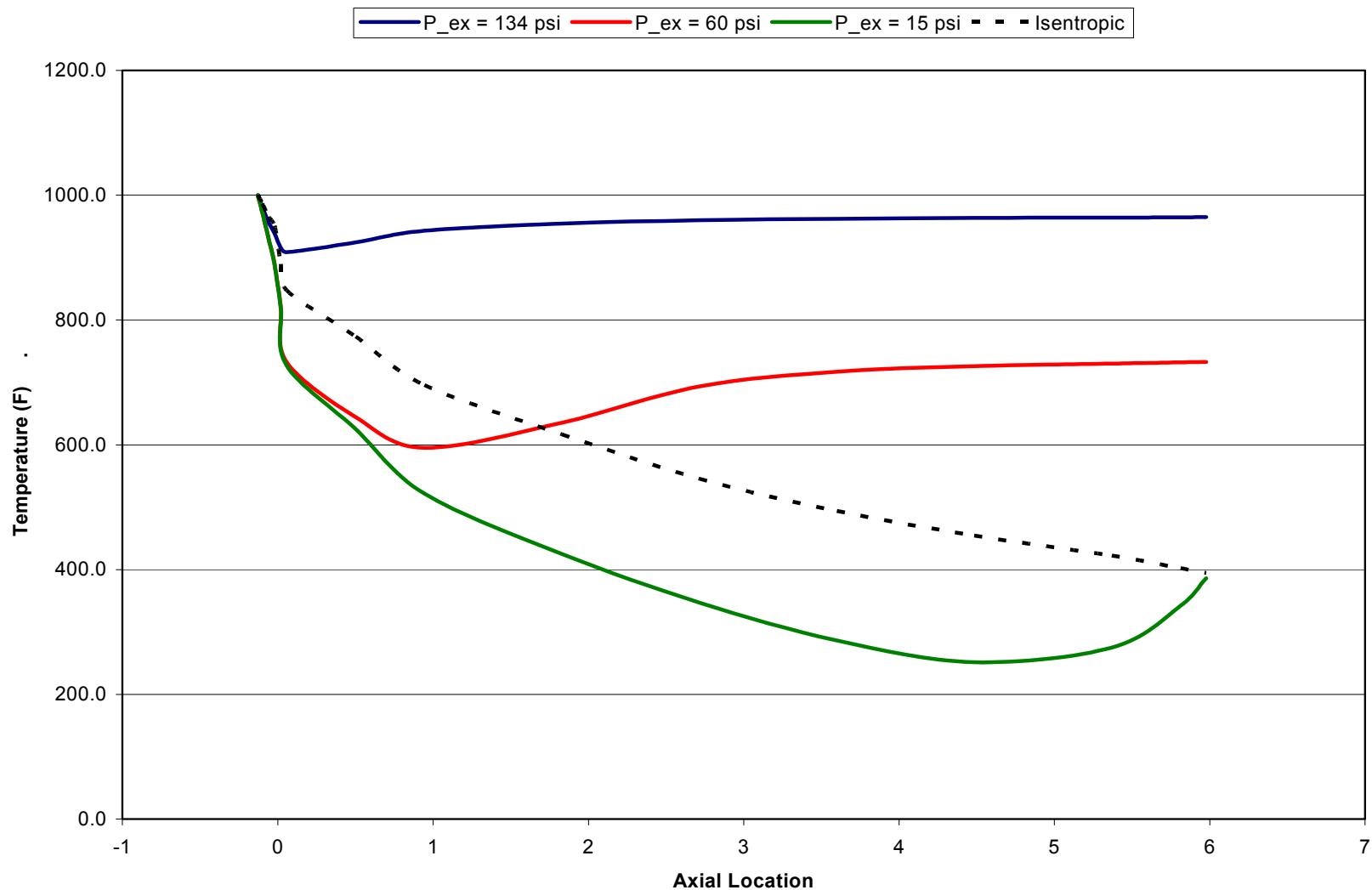
GFSSP Modeling – CD Nozzle Investigation



Density vs. Axial Location



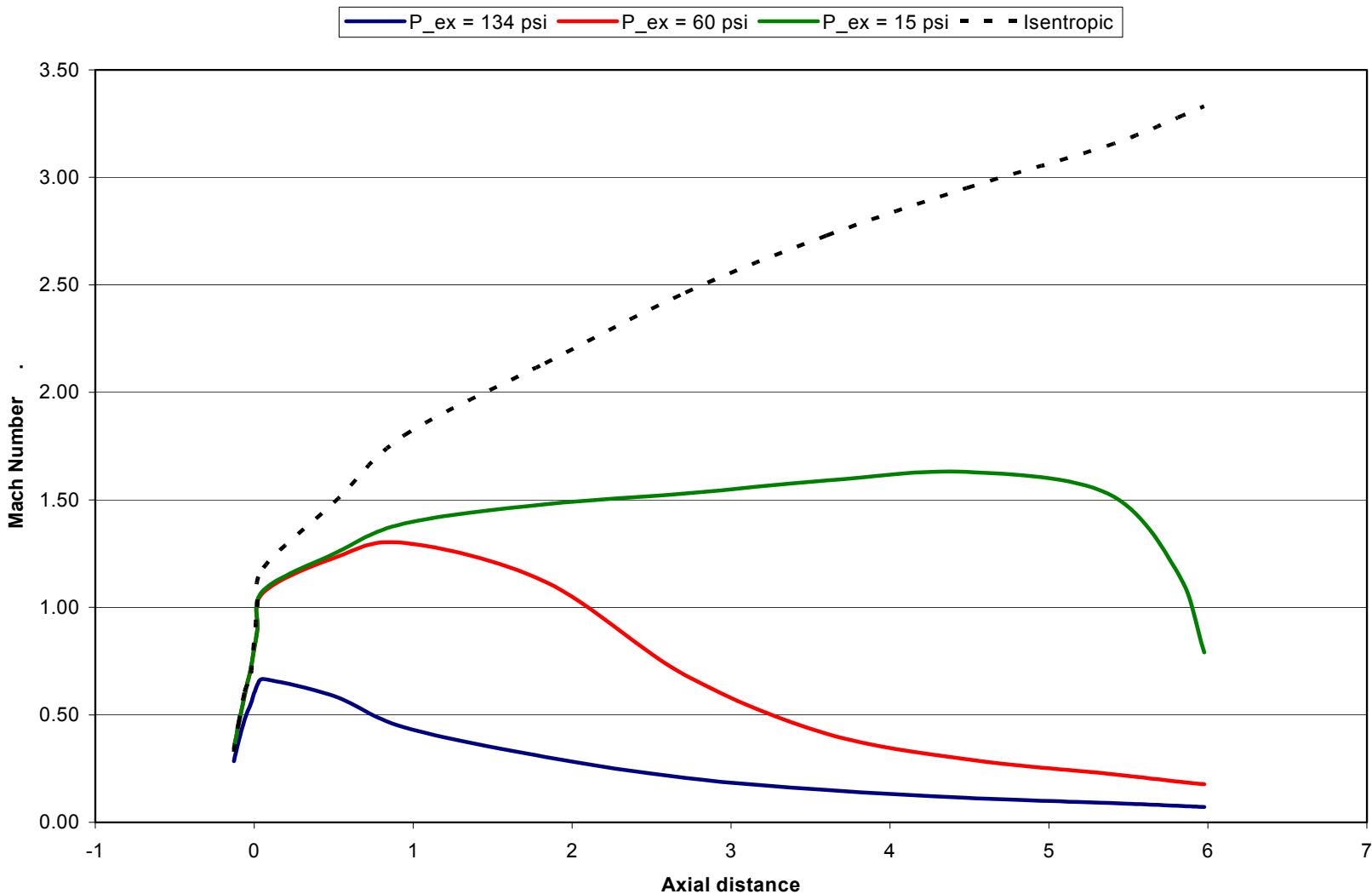
GFSSP Modeling – CD Nozzle Investigation



Temperature vs. Axial Location



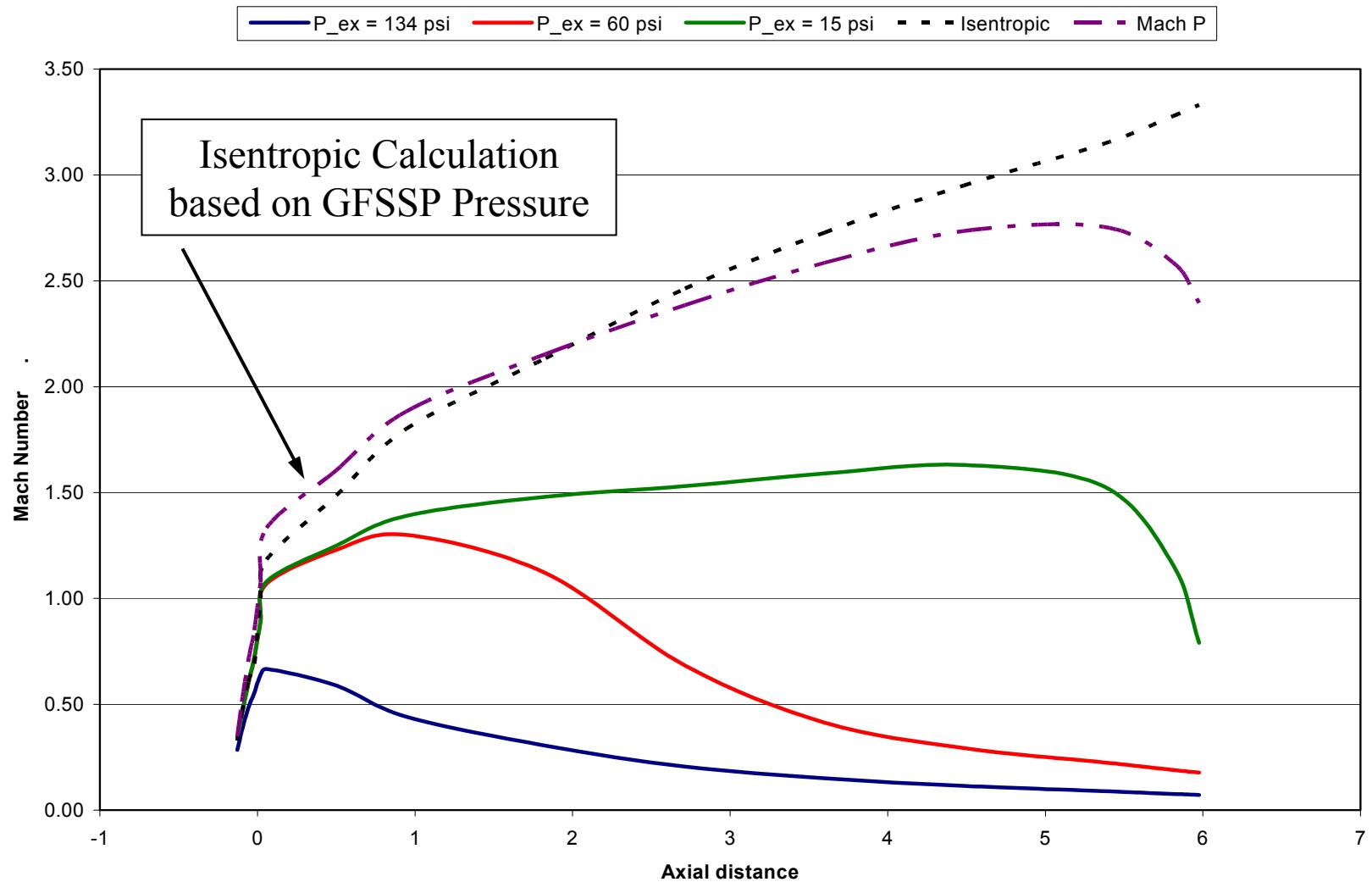
GFSSP Modeling – CD Nozzle Investigation



Mach Number vs. Axial Location



GFSSP Modeling – CD Nozzle Investigation



Mach Number vs. Axial Location (Modified)



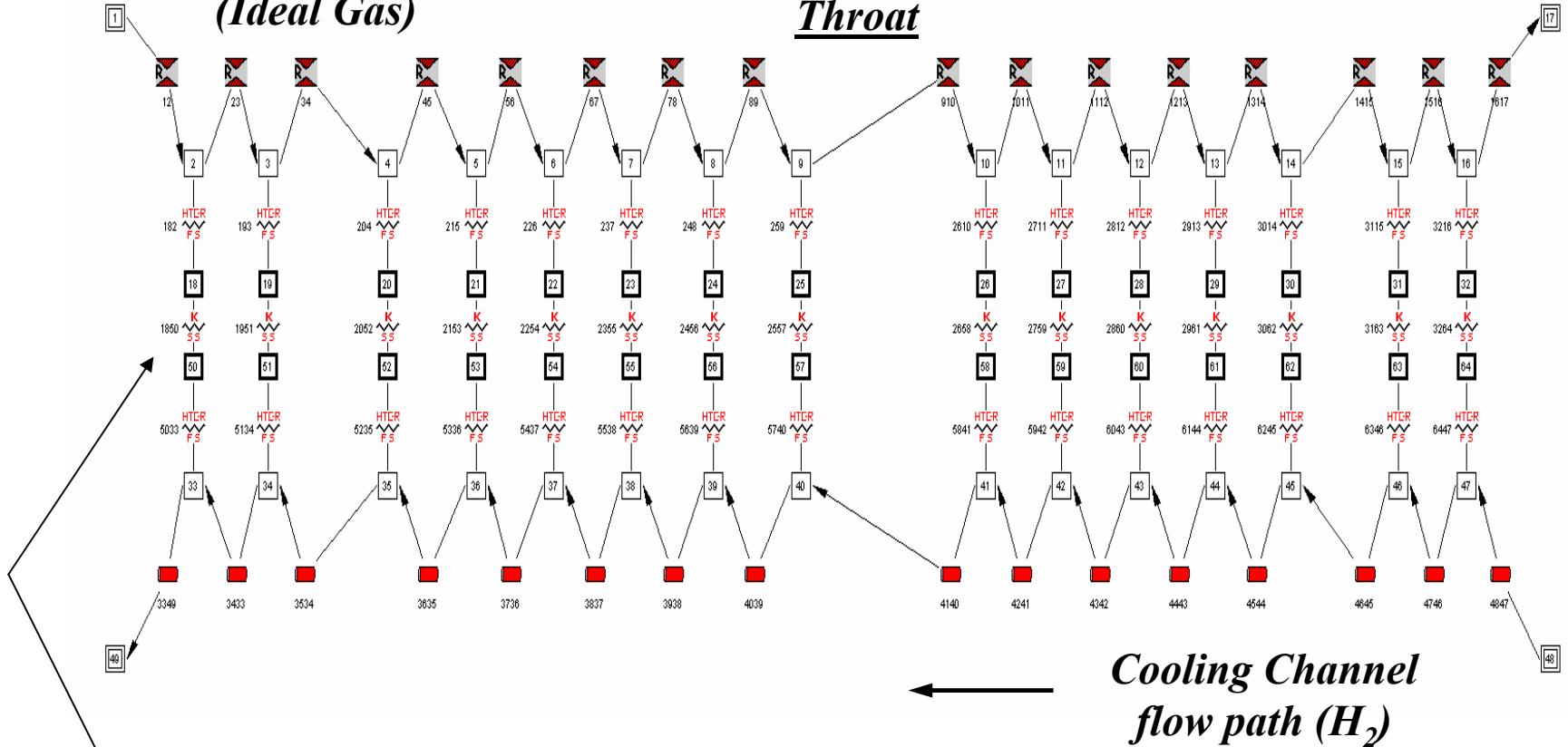
VTASC Regen. Cooling Model



Nozzle flow path
(Ideal Gas)



Throat



Solid (nozzle wall) nodes

Nozzle flow path, Coolant Channel, and wall thickness set to MCC geometry



SSME Regen. Cooling Problem



Preliminary Results

1. Demonstrated basic counter flow heat exchanger.
2. Created subroutine to calculate heat transfer coefficients
3. Could not correctly predict Mach number in diverging portion of C-D nozzle.
4. Mach number necessary for correct calculation of heat transfer coefficient using the Bartz equation. Used isentropic calculation for HCF subroutine using GFSSP predicted pressure.
5. Model became complex as geometry, multiple fluid, and MCC operating conditions were applied.
...Convergence became difficult to achieve and the time required was too large for use with SSME power balance models.



SSME Regen. Cooling Problem



NOTE:

- Used a beta version of the GFSSP code with conjugate heat transfer.
- Used “2nd Law” option for solution control. New version has improved enthalpy (1st Law option) calculation for compressible flow.
- Investigation of this problem is continuing.



Closed Circuit Modeling of Liquid Metal

**Alok Majumdar
ER43/NASA/MSFC**

**Users Group Meeting
October 26, 2004**



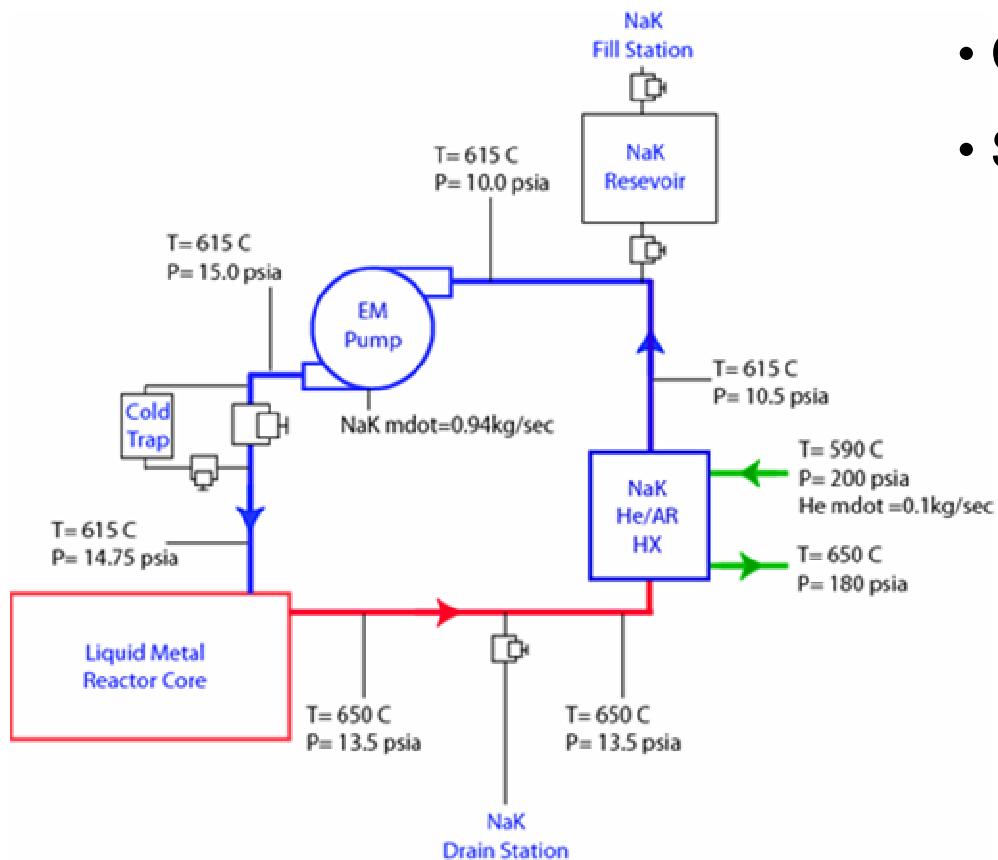
CONTENT

- Introduction
- New Features
 - Property Table
 - Electro Magnetic Conduction Pump
 - Closed Circuit Modeling
 - Fixed Flowrate
- Results
- Summary



Introduction

NaK – Helium System

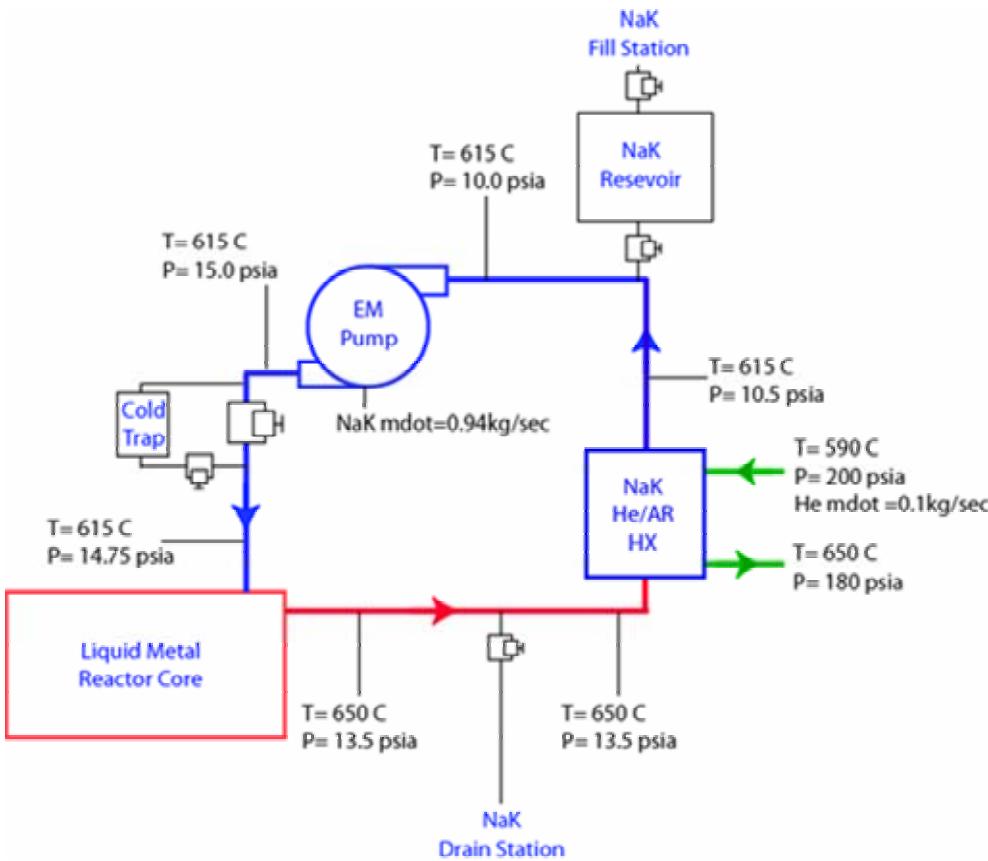


Objectives

- Calculate Flowrate
- State point properties



New Features



1. Property Look up Table for NaK
2. Electro-Magnetic Conduction Pump
3. Closed Circuit Model
4. Fixed Helium Flowrate



NaK Property Table

		Table for Specific Heat (Btu/lb-Deg R)					
No. of pressure points	15	30	No. of temperature points				
Pressure	→	0.5100E+03 0.7600E+03 0.1010E+04 0.1260E+04 0.1385E+04 0.1560E+04 0.6000E+01 0.2210E+00 0.2130E+00 0.2090E+00 0.2083E+00 0.2099E+00 0.2130E+00	0.5600E+03 0.8100E+03 0.1060E+04 0.1285E+04 0.1410E+04 0.1660E+04 0.2300E+00 0.2190E+00 0.2120E+00 0.2087E+00 0.2087E+00 0.2100E+00 0.2105E+00	0.6100E+03 0.8600E+03 0.1110E+04 0.1310E+04 0.1435E+04 0.1760E+04 0.2280E+00 0.2170E+00 0.2110E+00 0.2085E+00 0.2090E+00 0.2105E+00 0.2110E+00	0.6600E+03 0.9100E+03 0.1160E+04 0.1335E+04 0.1460E+04 0.1860E+04 0.2250E+00 0.2160E+00 0.2105E+00 0.2083E+00 0.2093E+00 0.2110E+00 0.2120E+00	0.7100E+03 0.9600E+03 0.1210E+04 0.1360E+04 0.1510E+04 0.1902E+04 0.2230E+00 0.2150E+00 0.2100E+00 0.2080E+00 0.2097E+00 0.2120E+00	Temperature

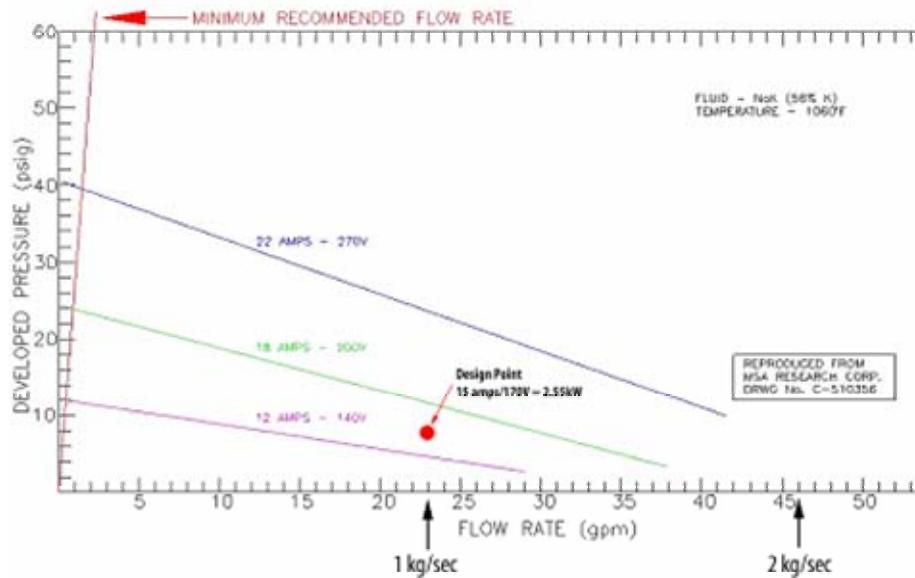
Property Tables are required for

- Density
- Conductivity
- Enthalpy
- Entropy
- Specific Heat
- Specific Heat Ratio
- Viscosity



Electro-Magnetic Conduction Pump

Pump Characteristic Curve



Pump Pressure Rise
is a function of:

- Flowrate
- Voltage/Current



User Subroutine for Modeling Electro-Magnetic Conduction Pump

SUBROUTINE SORCEF

Read Pump
Performance Data
From Table

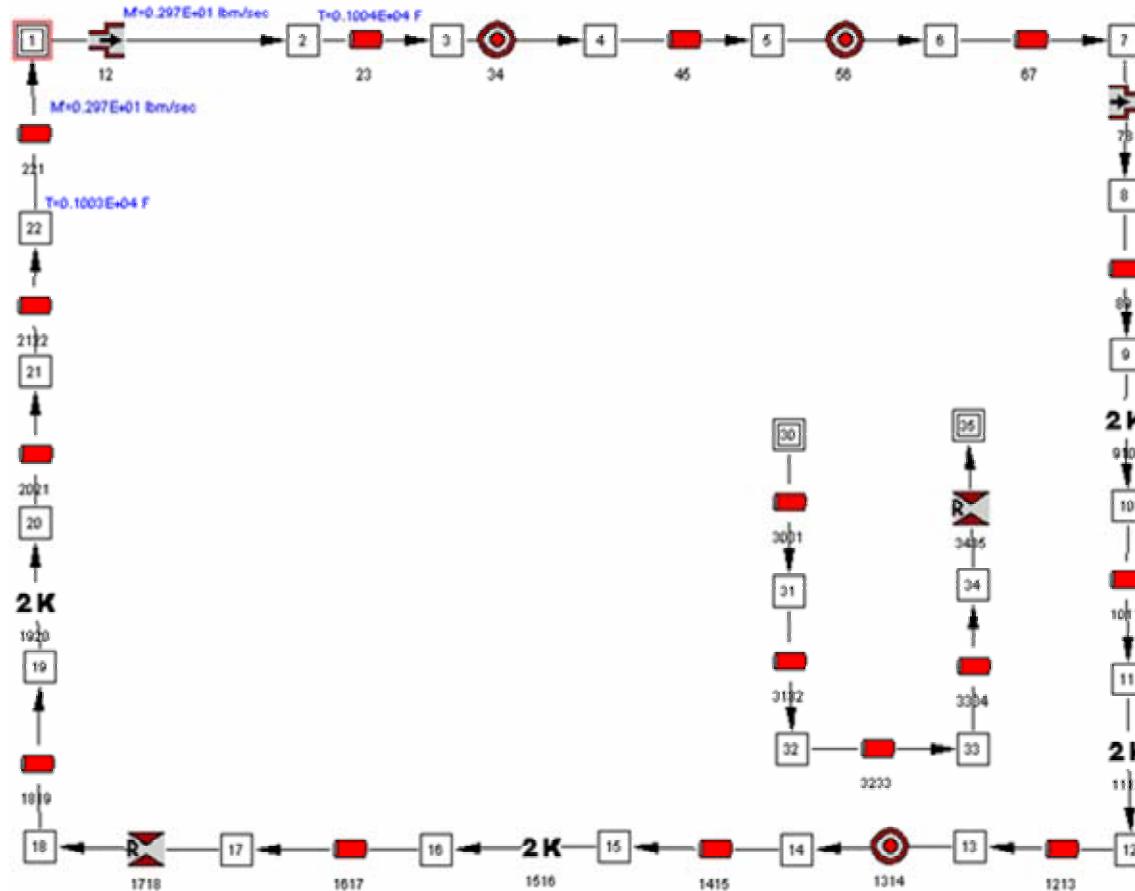
```
C      ADD CODE HERE
C      MODELING OF THERMO-ELECTRIC PUMP
DIMENSION VOLT(50),FLWTE(50),DPTE(50,50)
LOGICAL UNREAD
DATA VOLTIN/170/
C      READ PUMP CHARACTERISTIC DATA FROM FILE
IF (ITER.EQ.1.AND. (.NOT. UNREAD)) THEN
OPEN (NUSR1,FILE='nak_58_pump.dat',STATUS='UNKNOWN')
READ(NUSR1,*) NFLW,NVOLT
READ(NUSR1,*) (VOLT(JJ),JJ=1,NVOLT)
DO II = 1,NFLW
  READ(NUSR1,*) FLWTE(II),(DPTE(II,JJ),JJ=1,NVOLT)
ENDDO
UNREAD = .TRUE.
ENDIF ! IF (ITER.EQ.0)..
```

Interpolate data to find
DELP

```
C      IF (IBRANCH(I) .EQ. 1718) THEN
      BRACKET THE FLOWRATE
IR=0
DO II =2,NFLW
  IF (FLOWR(I).GE.FLWTE(II-1).AND.FLOWR(I).LE.FLWTE(II)) THEN
    IR=II
    GO TO 100
  ENDIF
ENDDO
100 IF (IR.EQ.0) THEN
  IF (FLOWR(I).GT.FLWTE(NFLW)) IR=NFLW
  IF (FLOWR(I).LT.FLWTE(1)) IR=1
ENDIF
C      BRACKET THE VOLT
JR=0
DO JJ = 2,NVOLT
  IF (VOLTIN.GE.VOLT(JJ-1).AND.VOLTIN.LE.VOLT(JJ)) THEN
    JR=JJ
    GO TO 200
  ENDIF
ENDDO
200 IF (JR.EQ.0) THEN
  IF(VOLTIN.GT.VOLT(NVOLT)) JR=NVOLT
  IF(VOLTIN.LT.VOLT(1)) JR=1
ENDIF
C      CALCULATE DELPTE
FACTFLW=(FLOWR(I)-FLWTE(IR-1)) / (FLWTE(IR)-FLWTE(IR-1))
FACTV=(VOLTIN-VOLT(JR-1)) / (VOLT(JR)-VOLT(JR-1))
DELPTE=(1,-FACTFLW)*(1,-FACTV)*DPTE(IR-1,JR-1)
&           +FACTFLW*(1,-FACTV)*DPTE(IR,JR-1)
&           +FACTFLW*FACTV*DPTE(IR,JR)
&           +(1,-FACTFLW)*FACTV*DPTE(IR-1,JR)
TERM100=144*DELPTE*AREA(I)
```



Closed Circuit Modeling



- Cyclic Boundary Condition needs to be satisfied at Node 1
- This implies Temperature at Node 22 must be equal to Temperature at Node 1
- This must be achieved by iteration



Use of a new User Subroutine

Set Temperatures at Boundary node equal to upstream node

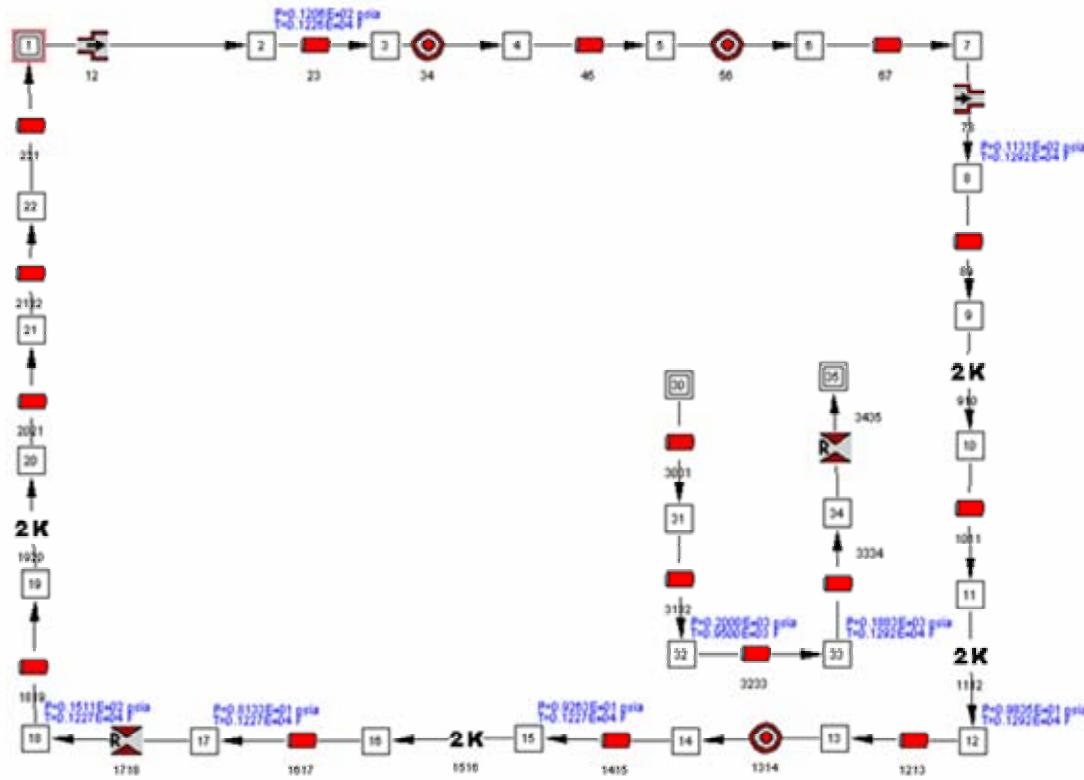
```
C*****  
C      SUBROUTINE USRADJUST(ITERADJ)  
C      PURPOSE: ADJUST BOUNDARY CONDITION OR GEOMETRY  
C*****  
*  
      INCLUDE 'COMBLK.FOR'  
C*****  
C      ADD CODE HERE  
      FLOWREQ= .1  
      RELAXAR=0.5  
      REPEAT = .FALSE.  
C      ADJUST TEMPERATURE TO SATISFY CYCLIC BOUNDARY CONDITION  
      NUMBER=1  
      CALL INDEXI (NUMBER, NODE, NNODES, IPN1)  
      NUMBER=22  
      CALL INDEXI (NUMBER, NODE, NNODES, IPN2)  
      DIFTEM=ABS (TF(IPN1)-TF(IPN2))/TF(IPN1)  
      TF(IPN1)=TF(IPN2)
```

Check for convergence

```
IF (MAX(DIFTEM,DIFFLW) .LT. 0.001.AND. ITERADJ.GT.2) THEN  
    REPEAT=.FALSE.  
ELSE  
    REPEAT=.TRUE.  
ENDIF  
WRITE(*,*) 'ITERADJ=',ITERADJ, 'DIFTEM = ', DIFTEM , 'DIFFLW = ',  
&           DIFFLW
```



Fixed Flowrate for Helium



- Helium Flowrate was maintained constant by Flow Regulating Valve
- A variable area choked orifice was used
- Area was adjusted in SUBROUTINE USRADJUST



User Subroutine for Flowrate adjustment

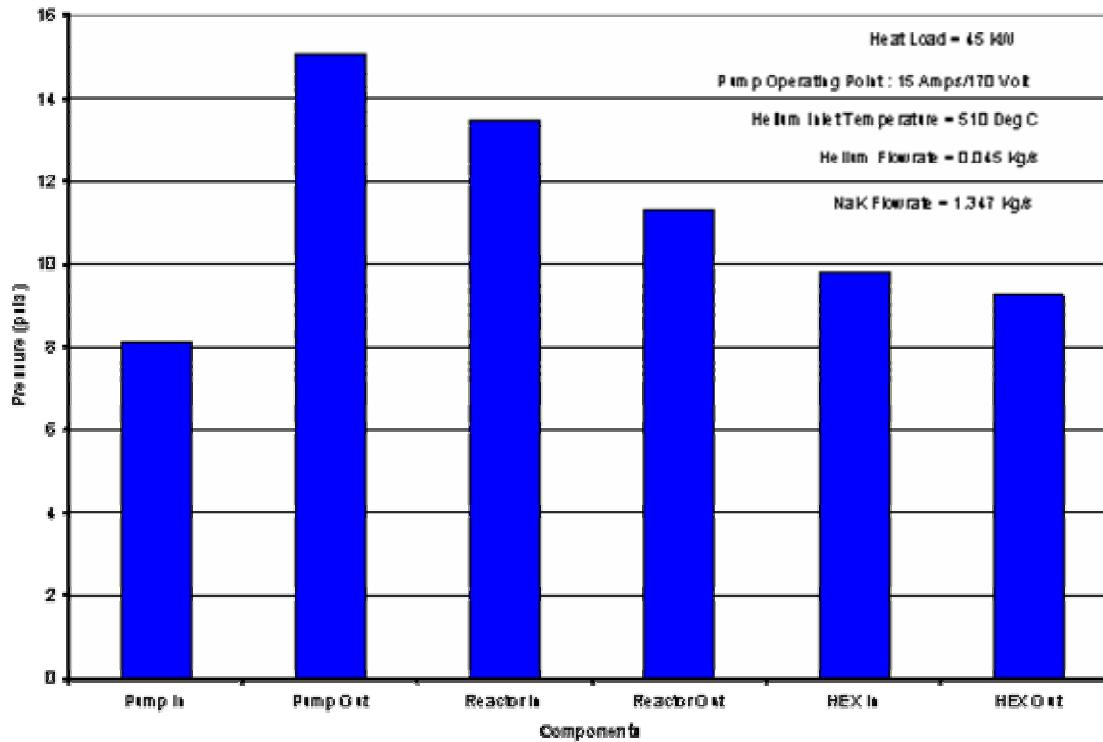
```
C      ADJUST AREA OF CHOKED ORIFICE TO REGULATE FLOWRATE  
NUMBER=3435  
CALL INDEXI (NUMBER,IBRANCH,NBR,IB)  
FLOWCALC = FLOWR (IB)  
  
IF (ITERADJ .EQ. 0) THEN  
    AREAOLD=AREA (IB)  
    FLWOLD=FLOWCALC  
    IF (FLOWCALC .GT. FLOWREQ) THEN ←  
        AREA (IB)=0.99*AREA (IB)  
    ELSE  
        AREA (IB)=1.01*AREA (IB)  
    ENDIF  
  
    ELSE  
  
C      CALCULATE GRADIENT  
DADMDT=(AREA (IB)-AREAOLD) / (FLOWCALC-FLWOLD)  
DIFFFLW=ABS (FLOWREQ-FLOWCALC) / FLOWREQ ←  
FLWOLD=FLOWCALC  
AREAOLD=AREA (IB)  
C      CORRECT AREA  
AREA (IB)=AREAOLD+RELAXAR*DADMDT*(FLOWREQ-FLWOLD)  
ENDIF
```

Define adjustment
of area in 1st
iteration

Determine the area
based on gradient in
subsequent iterations

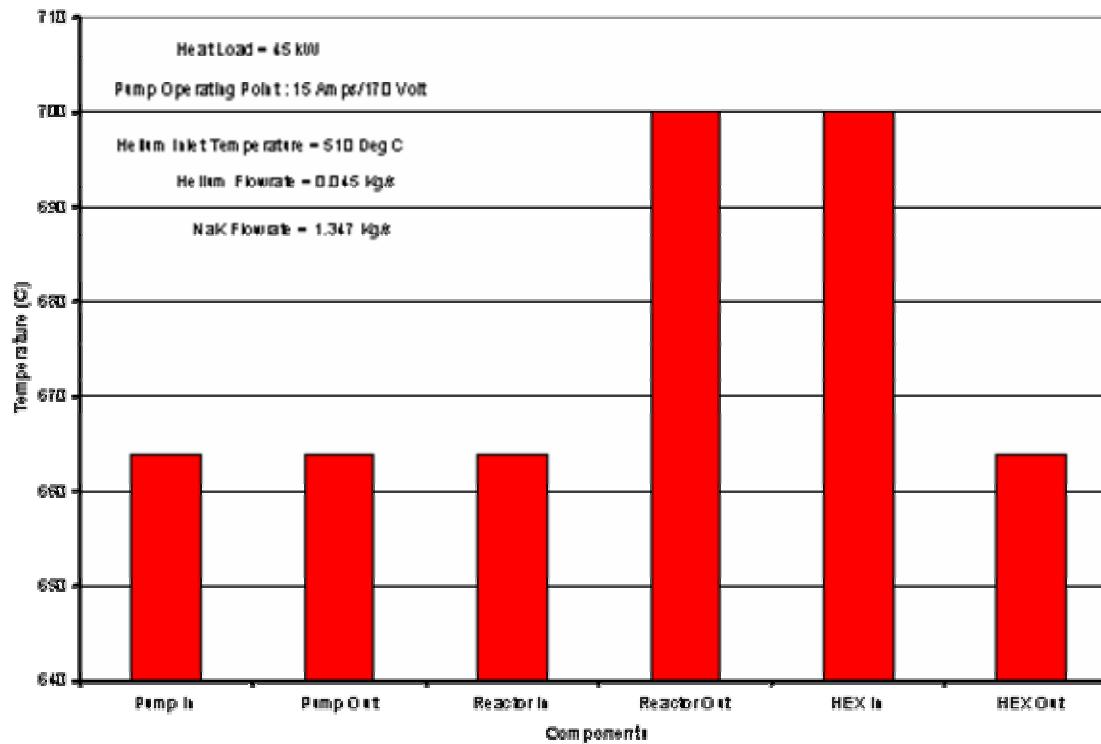


Pressure Distribution



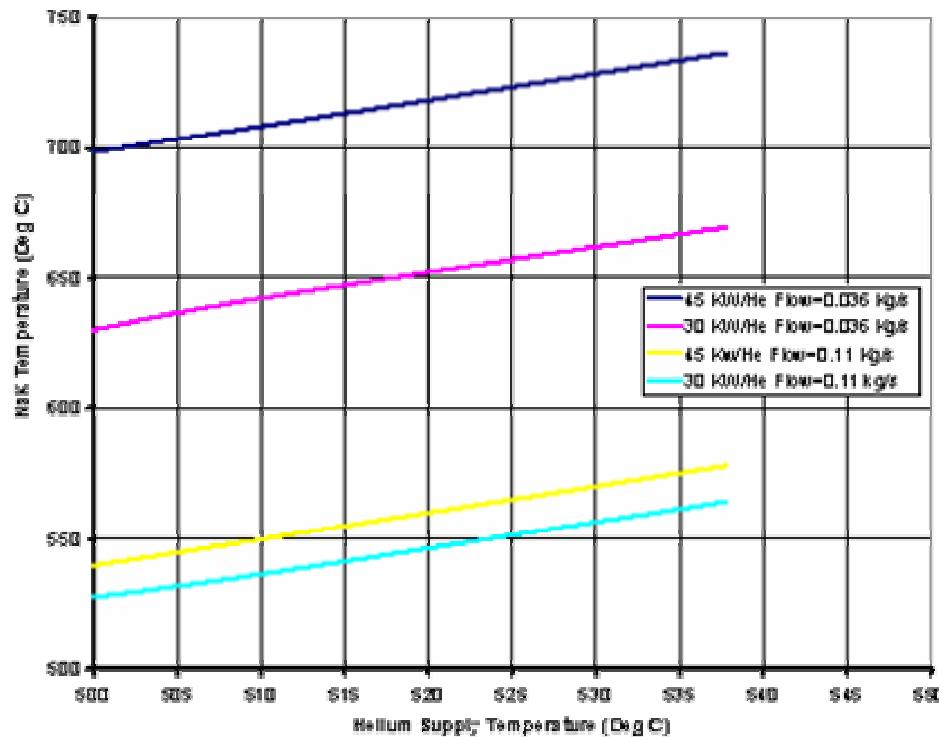


Temperature Distribution



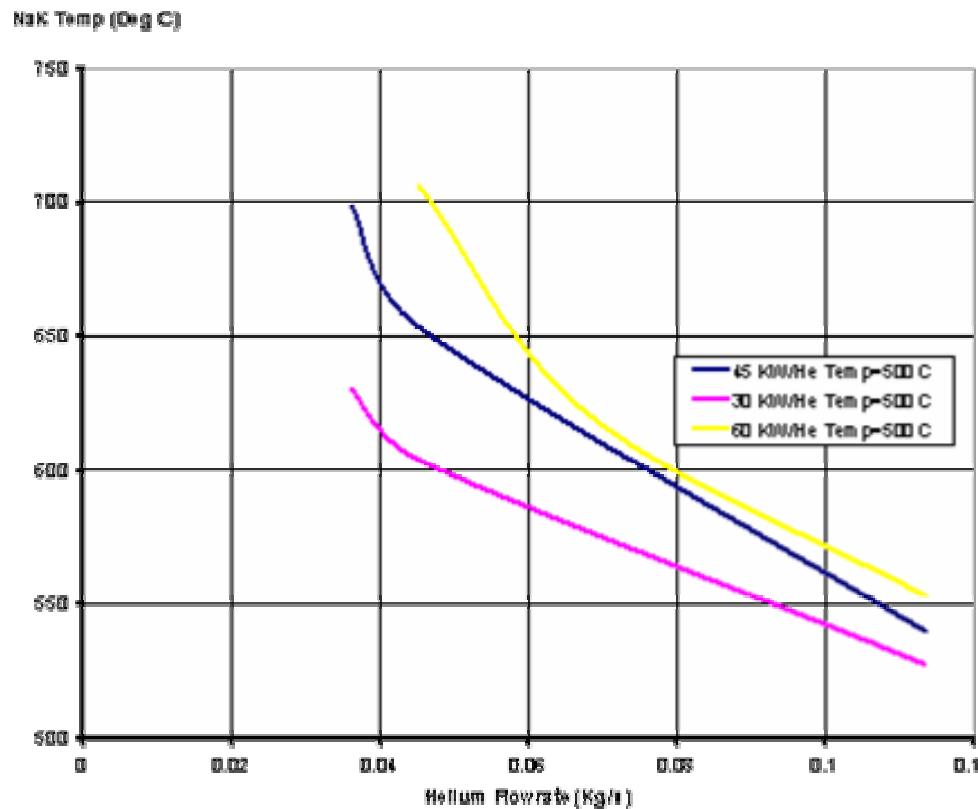


Helium Supply Temperature





Helium Flowrate





Summary

- NaK property was introduced through property table earmarked for RP-1
- Electro Magnetic Conduction pump was modeled in SUBROUTINE SORCEF
- Closed circuit model requires iterative adjustment to satisfy cyclic boundary condition
- Flow regulating valve also requires iterative adjustment of flow area
- SUBROUTINE USRADJUST (to be made available in the final release) performed iterations for cyclic boundary condition and flow regulating valve